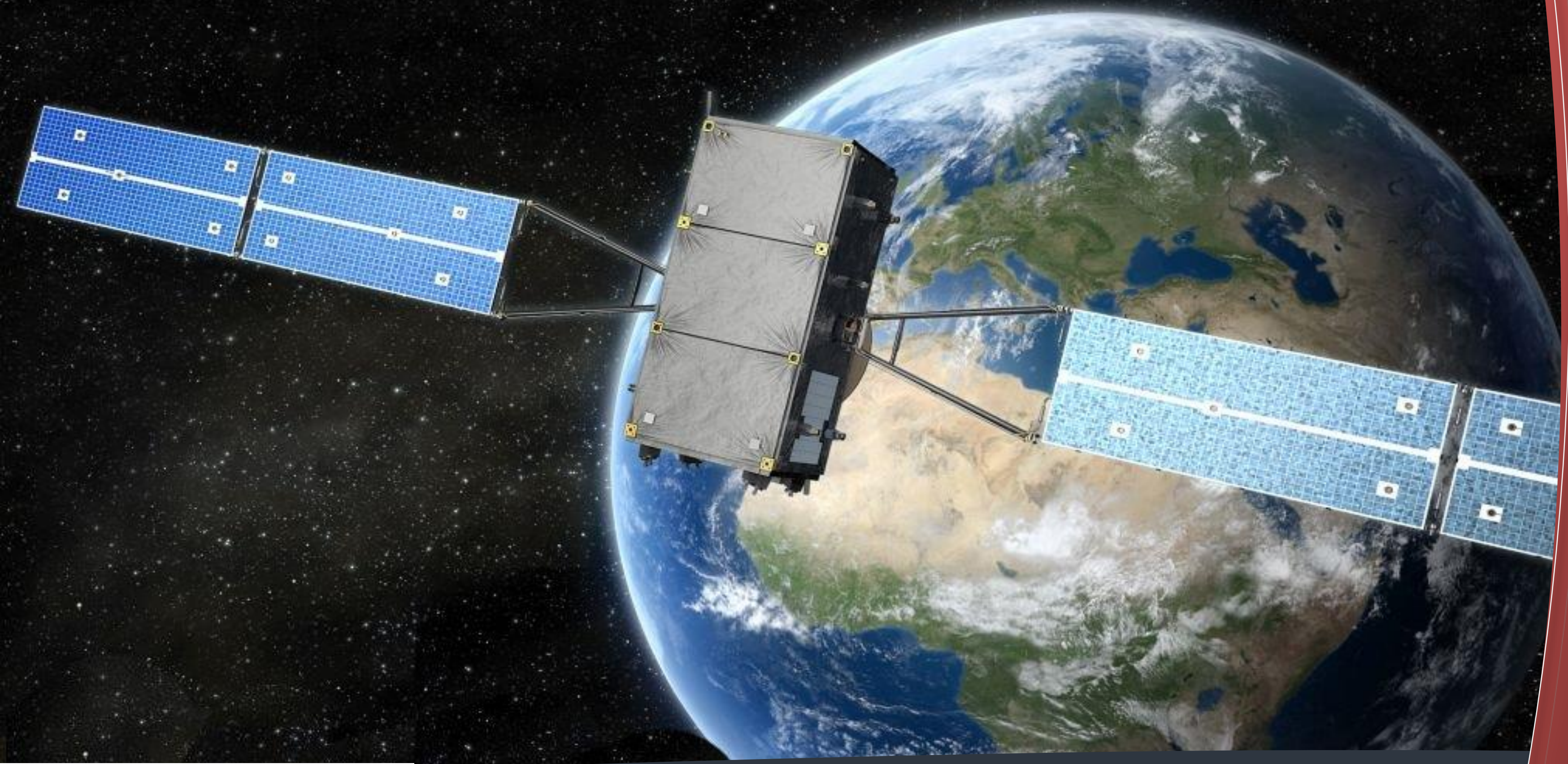
Wideband Circularly-Polarized Antennas for Satellite Communication



University of Kent

Professor Steven Gao

Chair of RF/Microwave Engineering

Acknowledgement

- Funding from EPSRC, UK
- Dr. Long Zhang, Dr. Qi Luo (University of Kent, UK), Dr. Shufeng Zheng (Xidian University), Dr. Fan Qin (Xidian University), Dr. Yuanming Cai and Prof. Yingzeng Yin (Xidian University)

Biography

University of Kent

Steven Gao is Professor and Chair of RF/Microwave Engineering, and Director of Postgradudate Research at School of Engineering and Digital Arts, University of Kent, UK. He started his career since 1994 while at China Research Institute of Radiowave Propagation. Then he worked as a Post-doc. Research Fellow at National University of Singapore (Singapore), a Research Fellow at Birmingham University (UK), a Visiting Scientist at ETHZ (Switzerland), a Visiting Fellow at Chiba University (Japan), a Visiting Scientist at University of California at Santa Barbara (US), a Senior Lecturer, Reader and Head of Antenna/Microwave Group at Northumbria University (UK), and Head of Satellite Antennas/RF System Group at Surrey Space Centre, University of Surrey (UK). He joined Kent as a Full Professor since Jan. 2013. He has 2 books, >300 papers in Journals and conferences and several patents. He is an Associate Editor of *IEEE Trans. on AP*, *Radio Science, IEEE Access*, and *IET Circuit, Device and System*. He was a Distinguished Lecturer of IEEE AP Society(2014-2016), General Chair of 2013 LAPC Conference, Guest Editor of *IEEE TAP* for Special Issue on "Antennas for Satellite Comm."(2015). He was a Plenary/Invited Speaker of some conferences (UCMMT'2017, AES'2014, SOMIRES'2013, APCAP'2014, etc). He is a Fellow of IET, UK, and a Fellow of Royal Aeronautical Society. He received IET Premium Award for the Best Paper in IET Microwave, Antennas and Propagation, 2016, etc. His main areas of expertise are in antennas, smart antennas, phased arrays, MIMO, and microwave/mm-wave systems.

Outline:

1. Introduction

2. A brief review of some recent development in wideband CP antennas

3. Case studies

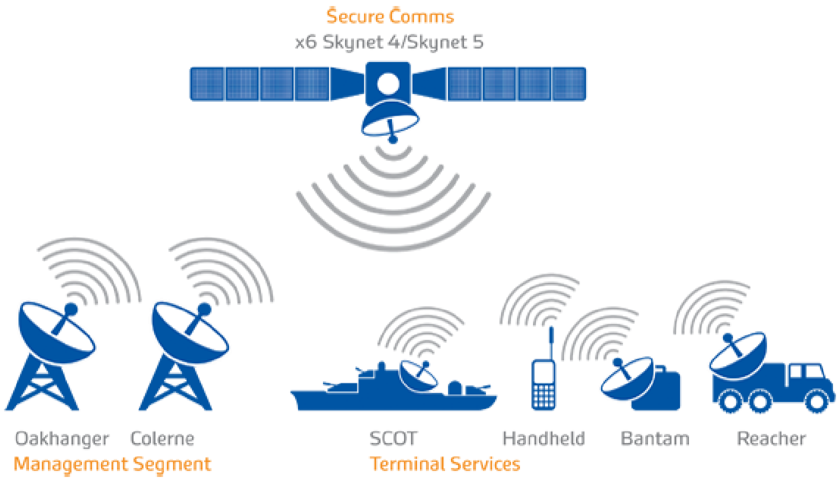
3.1 Wideband planar CP antenna using inverted-S element

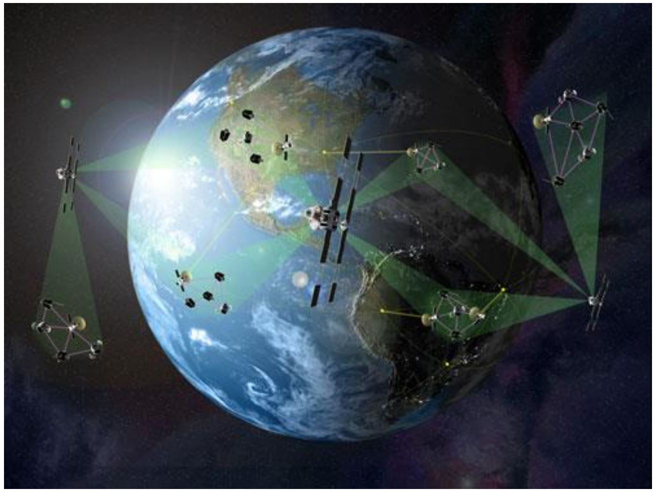
3.2 Single-layer wideband CP high-efficiency reflectarrays

4. Conclusions

1. Introduction

- Circularly polarized (CP) antennas are deployed in various wireless systems such as Satcom, GNSS, RFID, etc..


Secure Comms
x6 Skynet 4/Skynet 5
Oakhanger
Colerne
Management Segment
SCOT
Handheld
Bantam
Reacher
Terminal Services

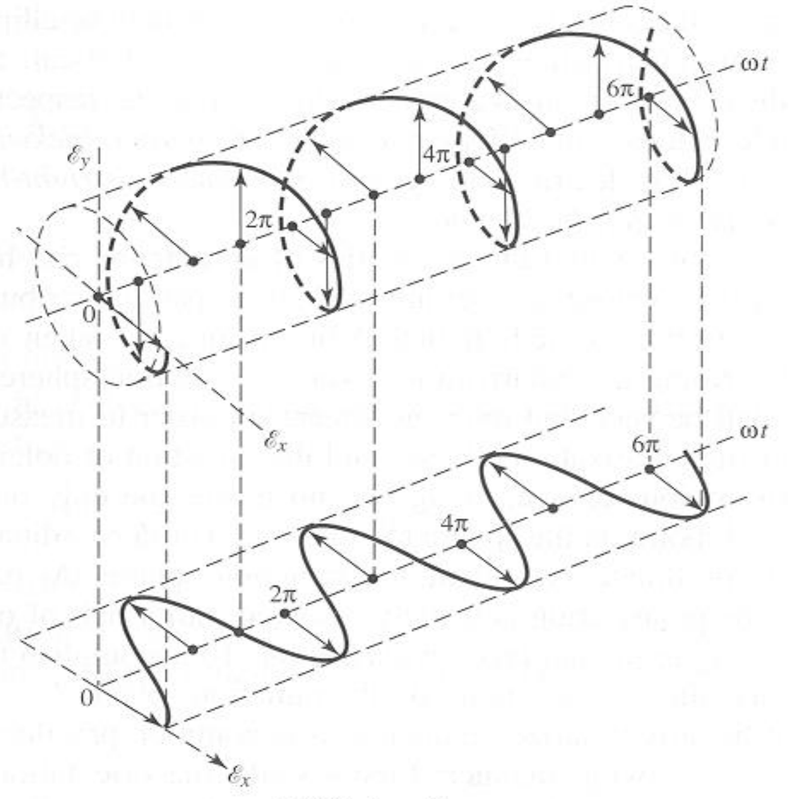


- **Advantages of CP antennas:**
  - Mitigation of multi-path fading
  - Immunity of Faraday rotation by ionosphere
  - Reduction of polarization mismatching between transmitting and receiving antennas

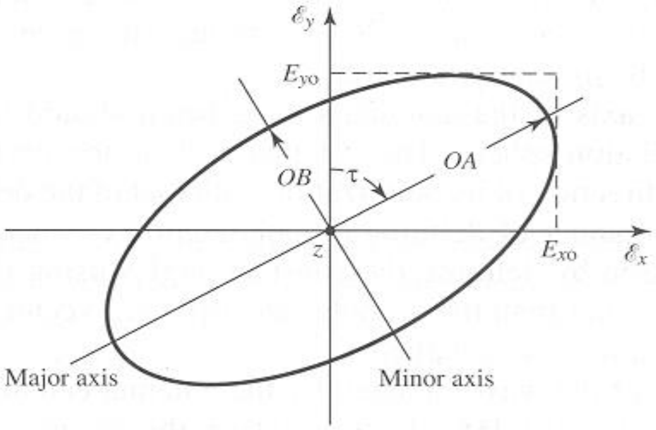
- **The principles to create a CP radiation**
  - $\vec{E}(\theta,\varphi) = \overrightarrow{E_\theta}(\theta,\varphi) \cdot e^{j\sigma_1} + \overrightarrow{E_\varphi}(\theta,\varphi) \cdot e^{j\sigma_2}$
  - $E_\theta(\theta,\varphi) = E_\varphi(\theta,\varphi)$
  - $\sigma_2 - \sigma_1 = \pm\frac{\pi}{2}$
- **Antennas for satellite communications have been dominated by reflectors, horns, waveguide and helix for many years**
- **Recently, many wideband CP antennas have been reported;**
- **A review of recent development in wideband CP antennas and arrays is needed**

Main challenges

- **Wide impedance bandwidth**
- **Wide Axial Ratio (AR) bandwidth**
  - The field vector traces out an ellipse
  - AR is the ratio of major to minor axes on the polarization ellipse


ωt
6π
4π
2π
ℰy
0
ℰx
ωt
6π
4π
2π
0
ℰx

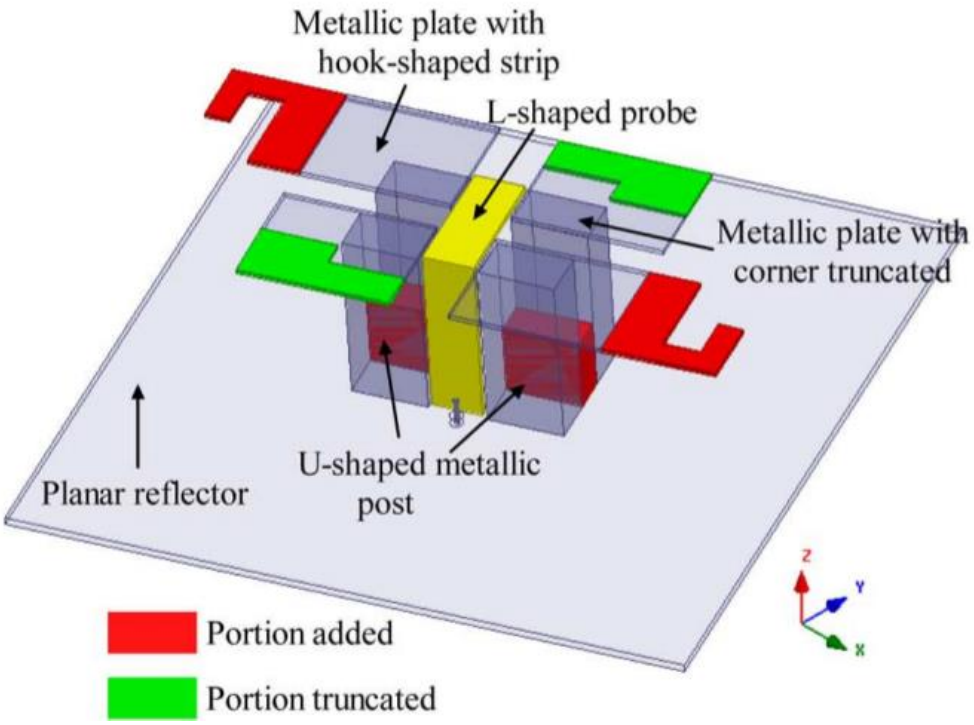
(a) Rotation of wave

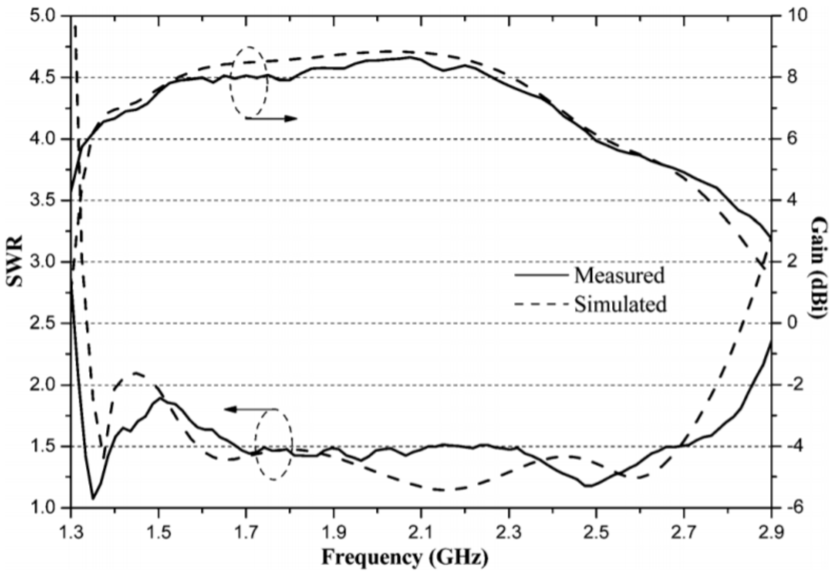

ℰy
Eyo
OA
OB
τ
z
Exo
ℰx
Major axis
Minor axis

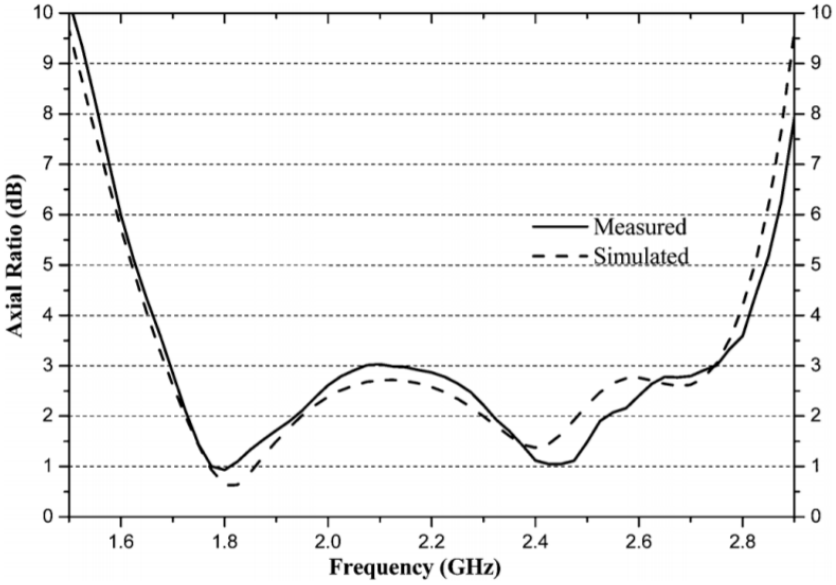
(b) Polarization ellipse

2. A Brief Review of Some Recent Development in Wideband CP Antennas

2.1 Magneto-Electric (ME) Dipole

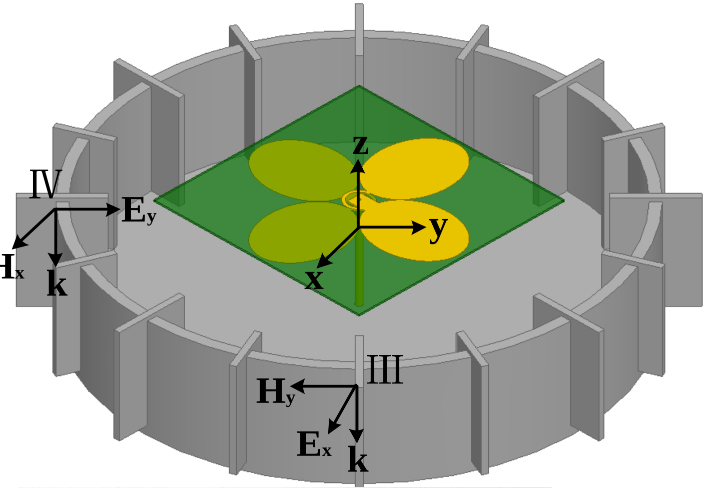

Metallic plate with hook-shaped strip
L-shaped probe
Metallic plate with corner truncated
U-shaped metallic post
Planar reflector
Z
Y
X
🟥 Portion added
🟩 Portion truncated

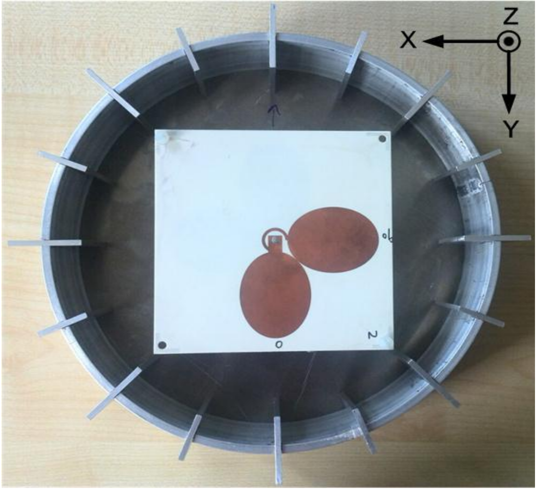


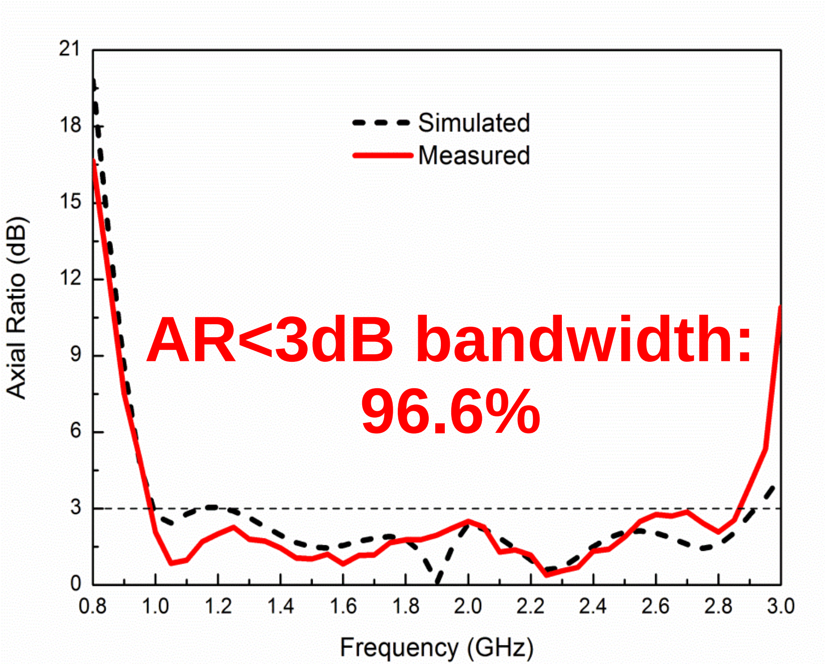


M. Li and K.-M. Luk, A wideband circularly polarized antenna for microwave and millimeter-wave applications, IEEE Transactions on Antennas and Propagation, 2014.

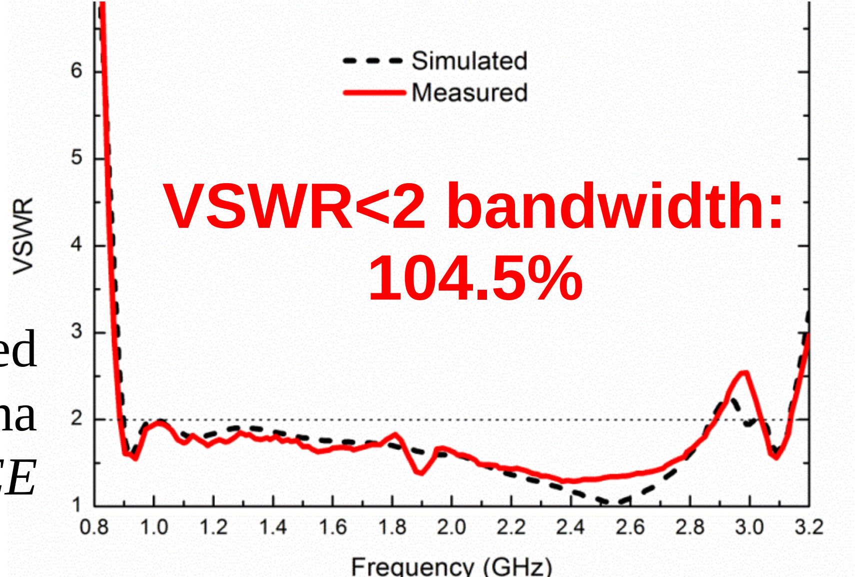
2.2 Wideband CP Crossed Dipoles







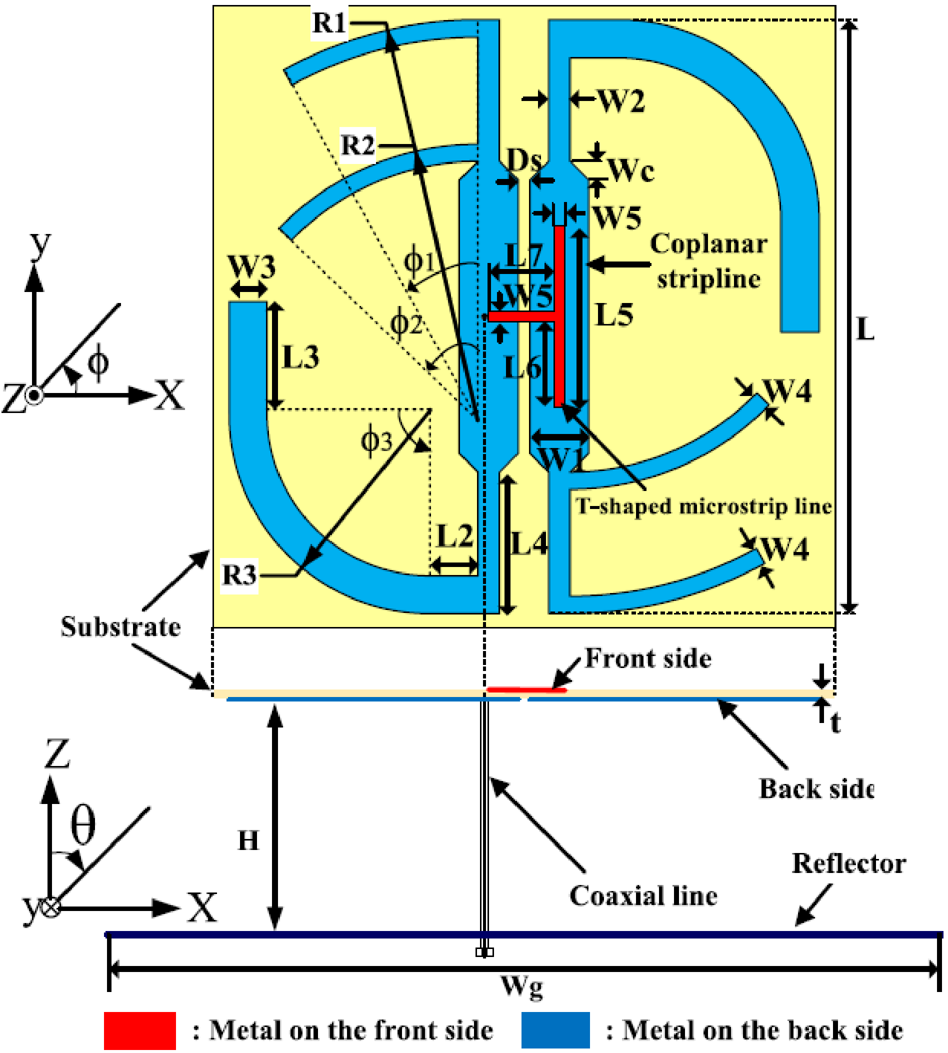
AR<3dB bandwidth: 96.6%

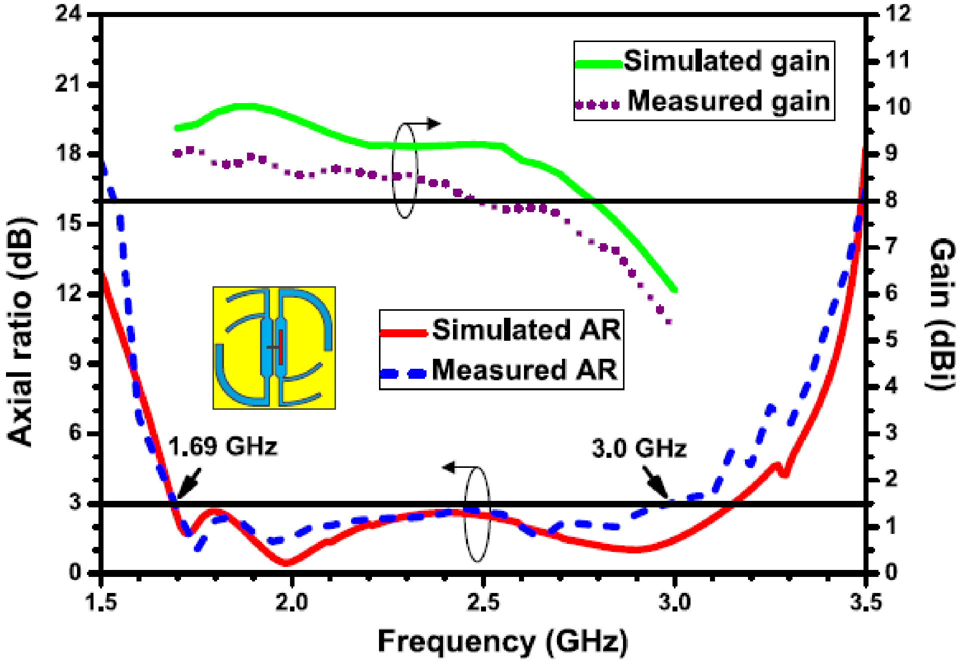


VSWR<2 bandwidth: 104.5%

L. Zhang, S. Gao, Q. Luo, et al., Single-Feed Ultra-Wideband Circularly Polarized Antenna with Enhanced Front-to-Back Ratio, *IEEE Trans. on AP*, Jan. 2016

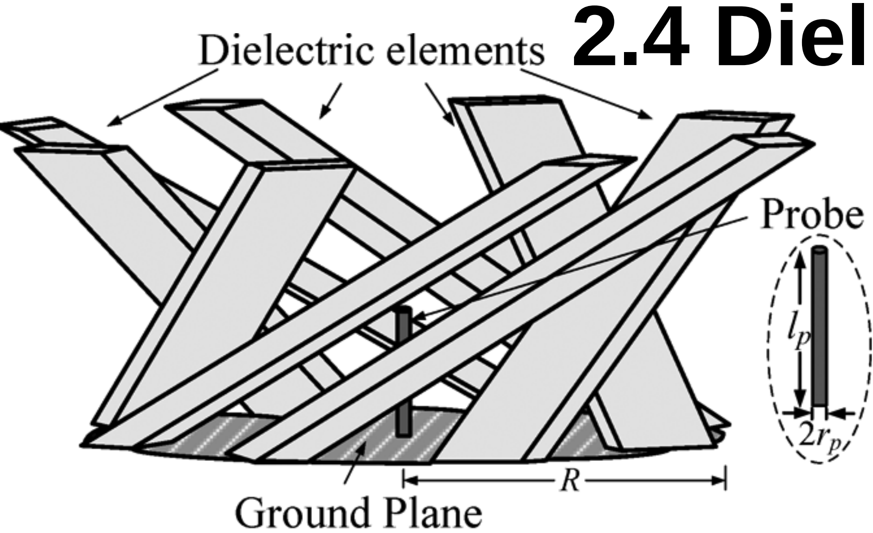
2.3 Off-Center-Fed Dipoles


R1
R2
R3
W2
Ds
Wc
W5
Coplanar stripline
W3
L7
W5
L5
ϕ1
ϕ2
L3
L6
L
W4
ϕ3
W1
T-shaped microstrip line
L2
L4
W4
y
ϕ
Z
X
Substrate
Front side
t
Back side
Z
θ
y
X
H
Coaxial line
Reflector
Wg
🟥 : Metal on the front side
🟦 : Metal on the back side

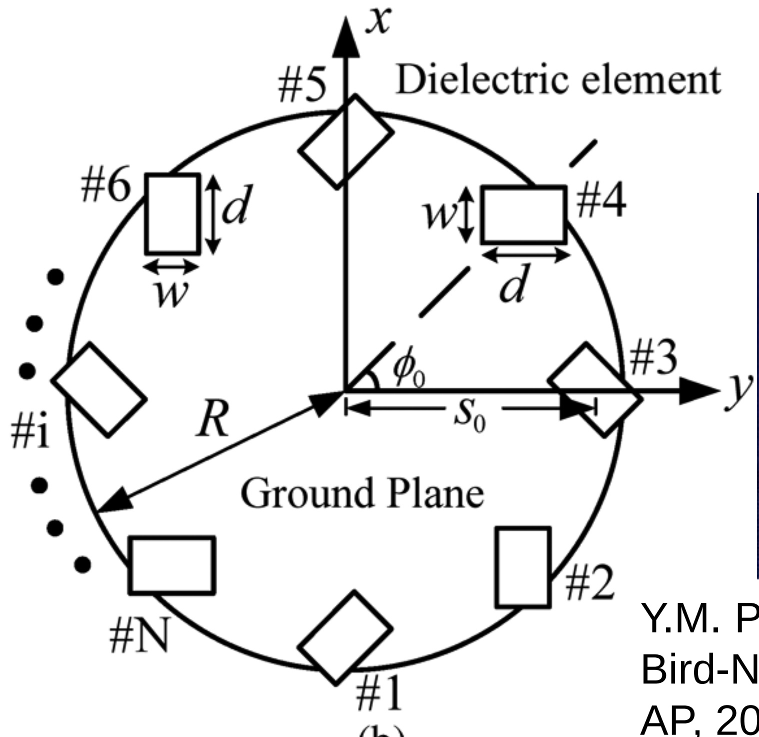


R. Li, et al, “A novel broadband circularly polarized antenna based on off-center-fed dipoles,” *IEEE Trans. Antennas Propag.*,Dec. 2015

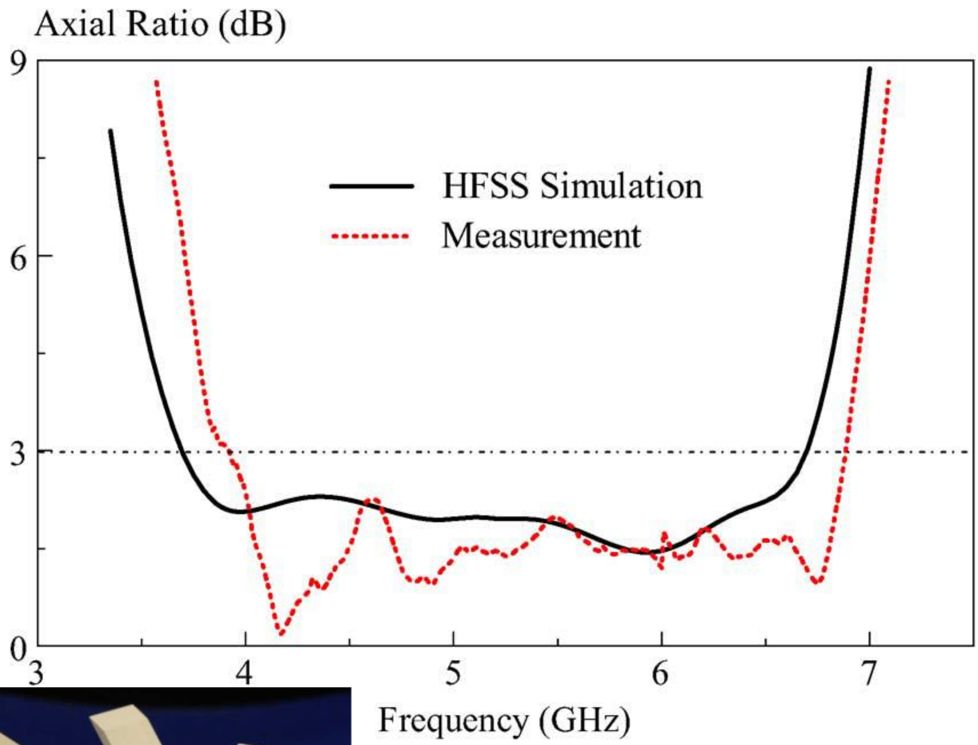
2.4 Dielectric Bird-Nest Antenna

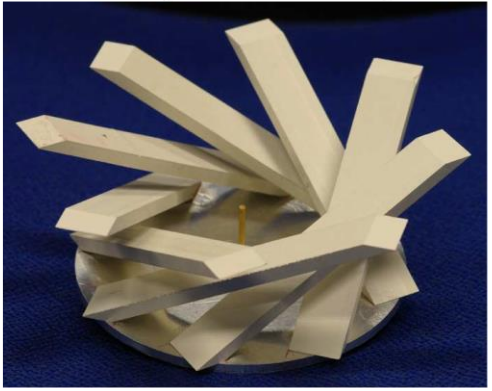

Dielectric elements
Probe
l_p
$2r_p$
Ground Plane
R

(a)


x
#5
Dielectric element
#6
d
w
w
#4
d
#3
ϕ_0
y
R
s_0
#i
Ground Plane
#N
#2
#1

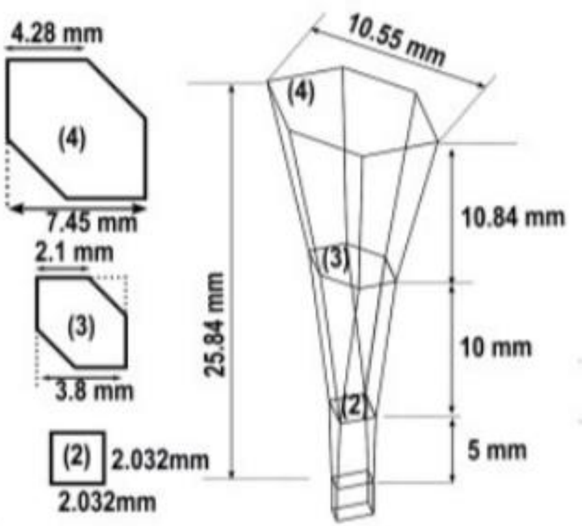
(b)

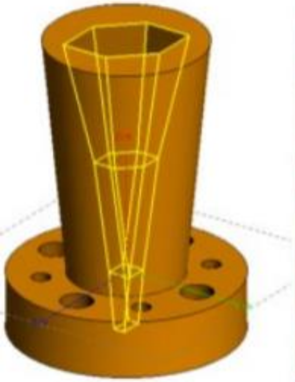


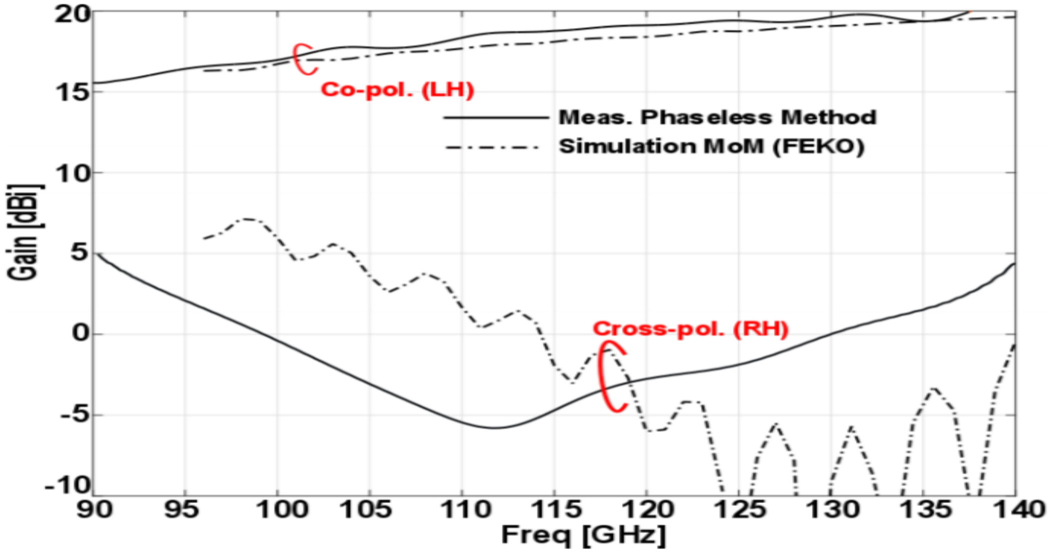


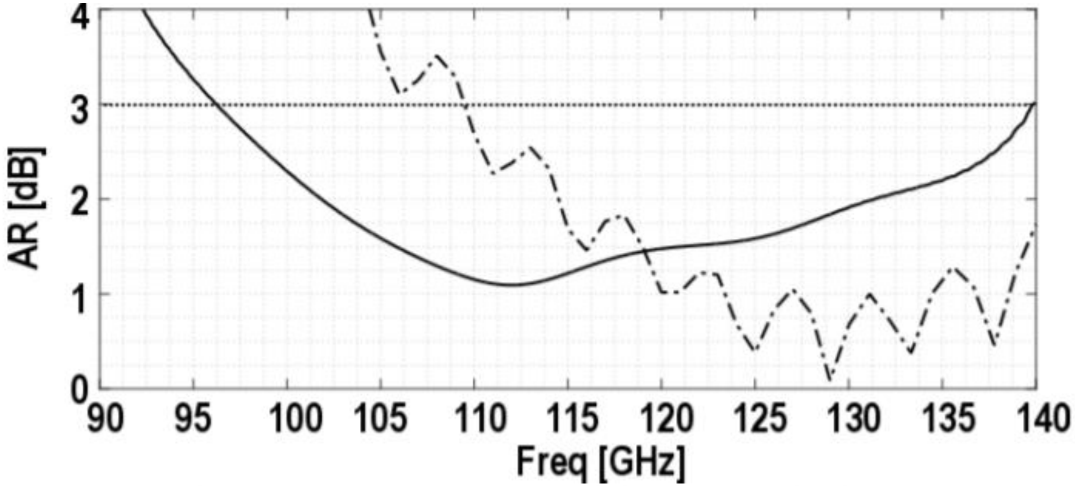
Y.M. Pan, K.W. Leung, Wideband Circularly Polarized Dielectric Bird-Nest Antenna With Conical Radiation Pattern, IEEE Trans AP, 2013

2.5 Wideband CP Horn


4.28 mm
(4)
7.45 mm
2.1 mm
(3)
3.8 mm
(2)
2.032mm
2.032mm
25.84 mm
10.55 mm
(4)
(3)
(2)
10.84 mm
10 mm
5 mm

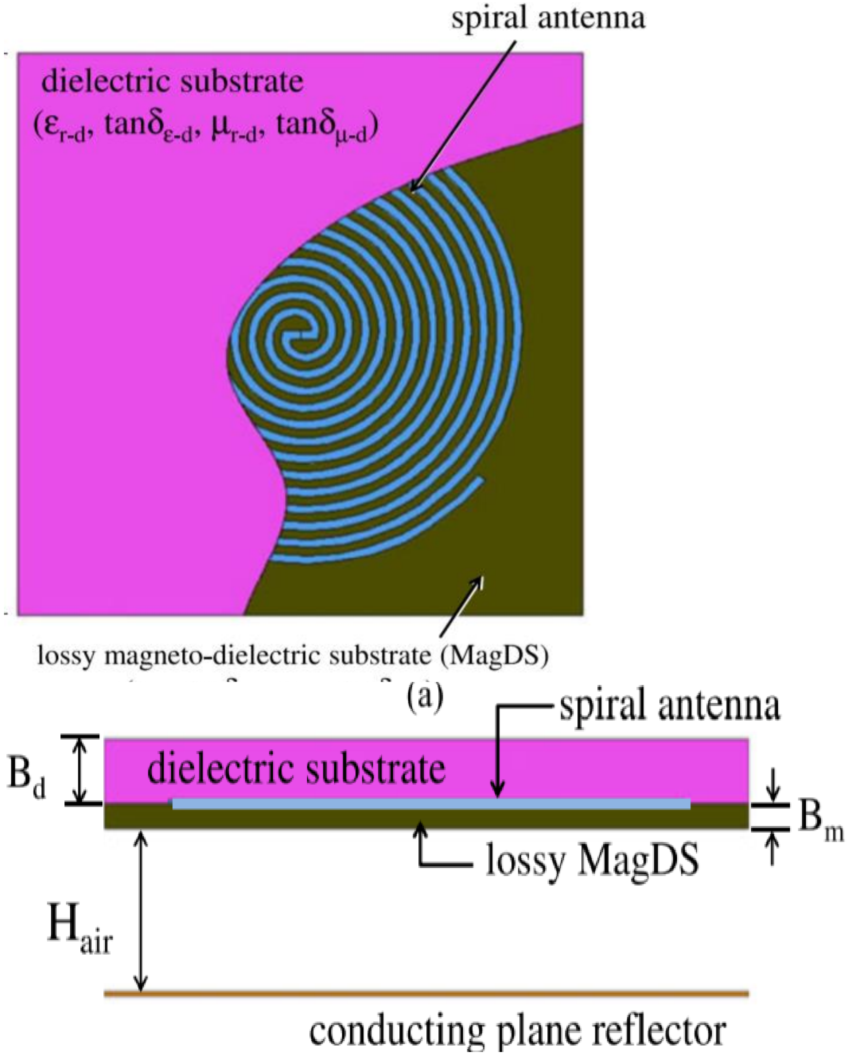


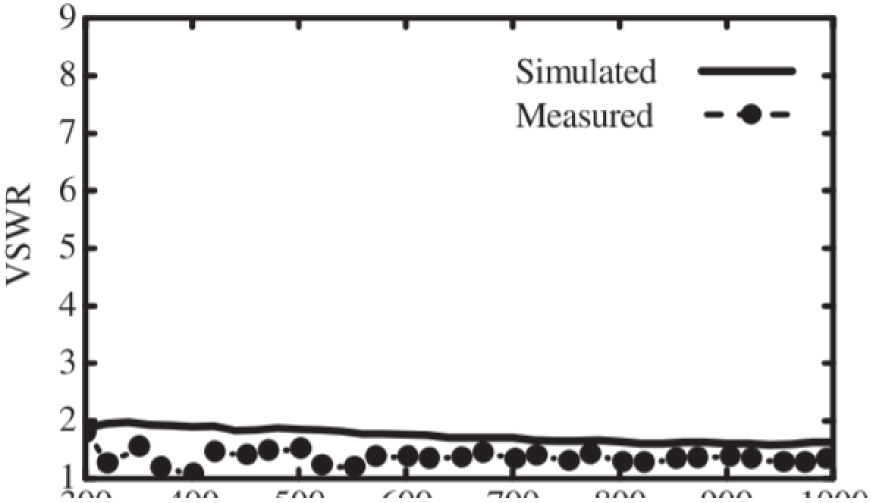


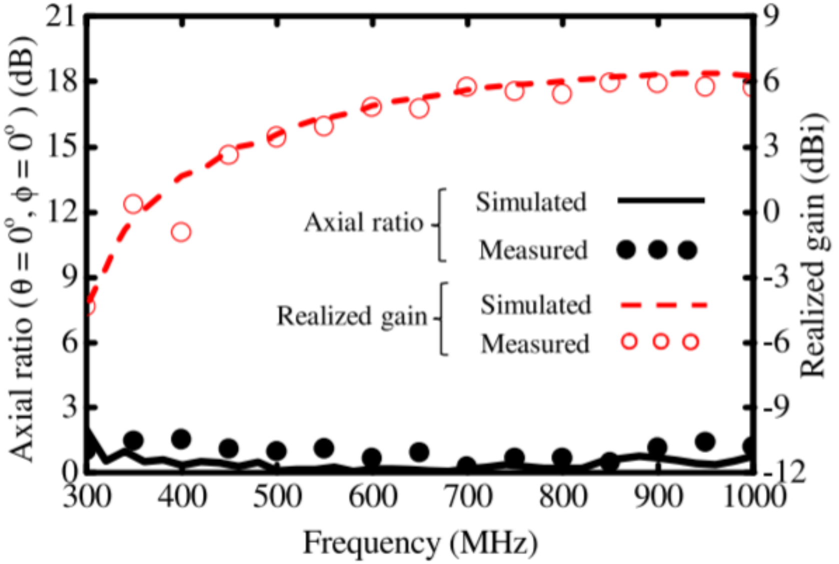


S. Bhardwaj and J. L. Volakis, Septum-less, hexagonal waveguide based circularly polarized horn antenna for mm-wave and terahertz band, Proc. of iWAT 2017

2.6 Low-Profile Spiral Antenna

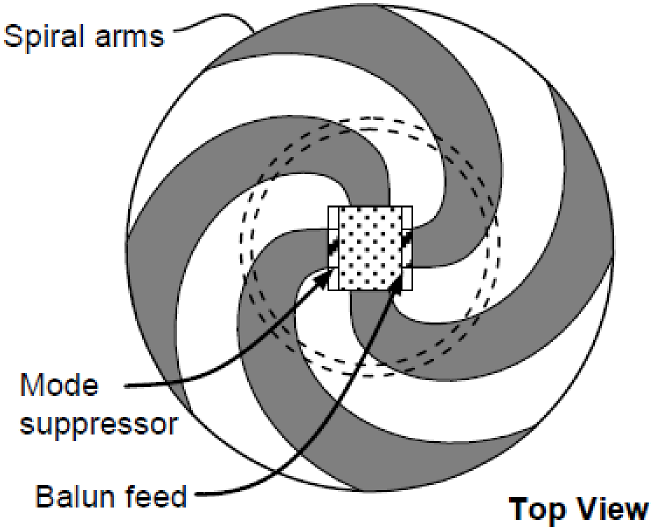

spiral antenna
dielectric substrate
($\varepsilon_{r\text{-}d}$, $\tan\delta_{\varepsilon\text{-}d}$, $\mu_{r\text{-}d}$, $\tan\delta_{\mu\text{-}d}$)
lossy magneto-dielectric substrate (MagDS)
(a)
spiral antenna
B_d
dielectric substrate
B_m
lossy MagDS
H_{air}
conducting plane reflector

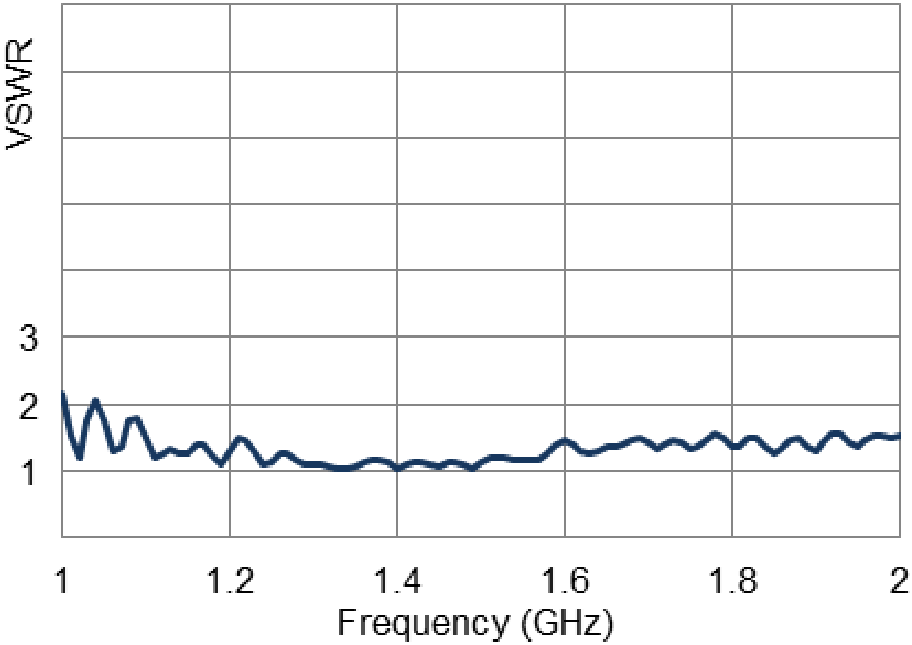


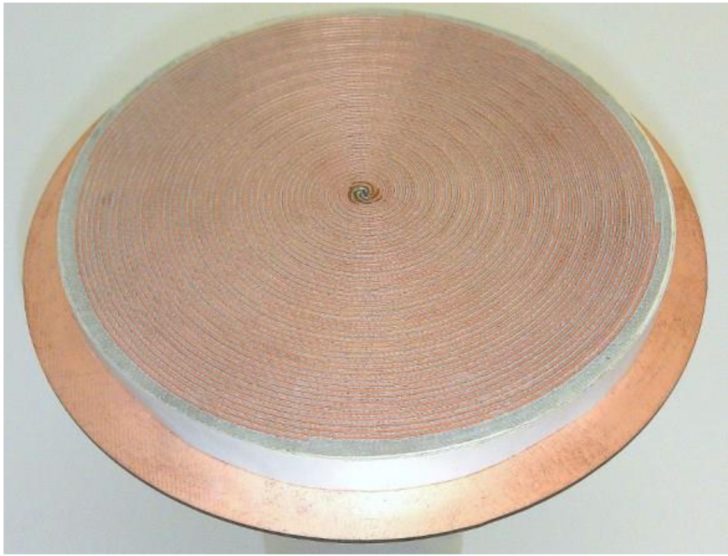


M. Tanabe, Y. Masuda, and H. Nakano, Low-Profile Spiral Antenna Placed on an Extremely Thin Magneto-Dielectric Substrate, IEEE Antennas and Wireless Propagation Letters, 2017, early access

2.7 Four-Arm Planar Travelling-wave Antenna

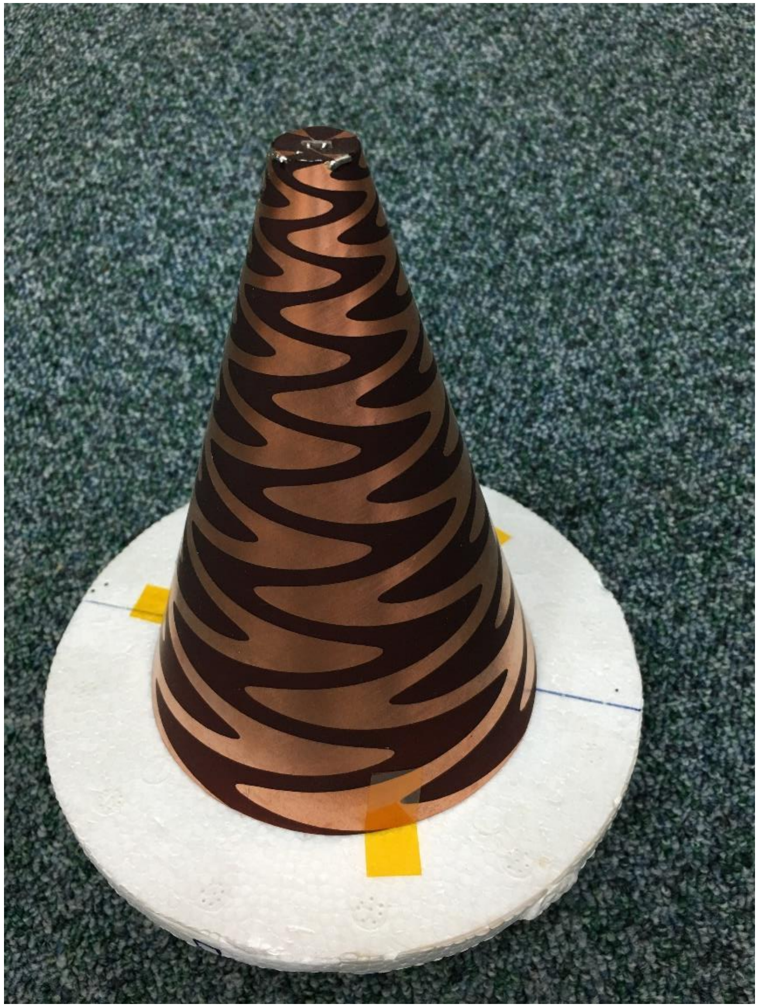

Spiral arms
Mode suppressor
Balun feed
Top View

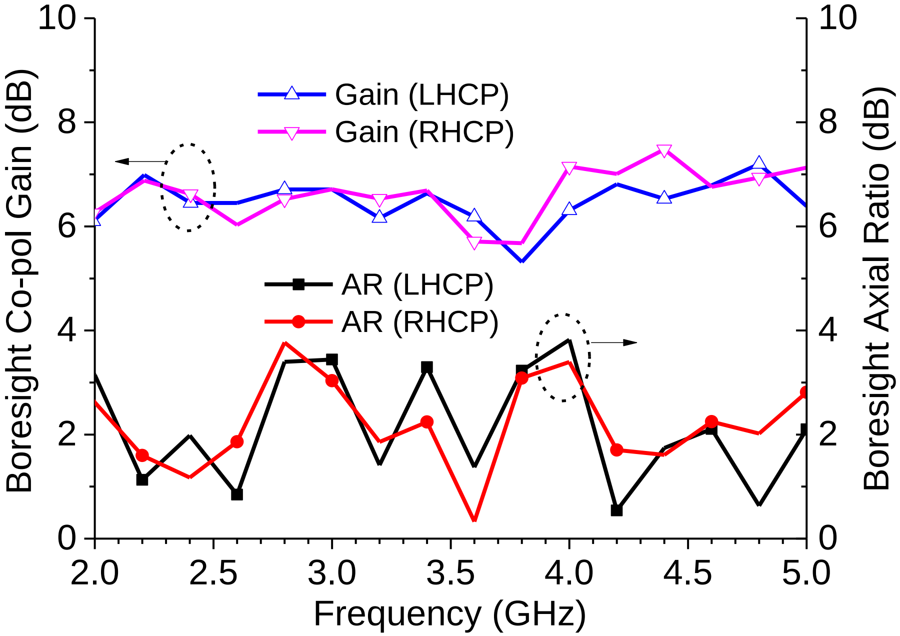




J.J.H. Wang. D.J. Triplett, A simple feed for 4-arm planar Traveling-Wave (TW) antennas—For GNSS (Global Navigation Satellite System) and other applications, Proc. of 2012 IEEE International Symposium on Antennas and Propagation, 2012

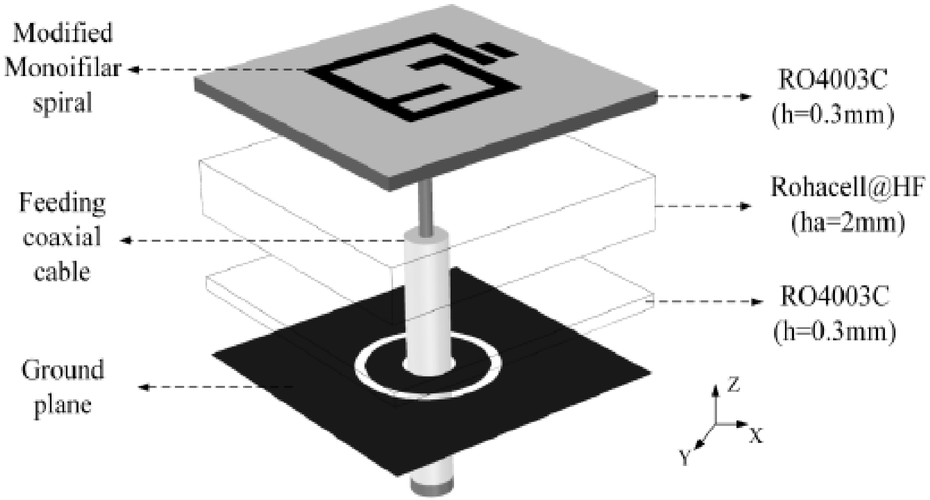
2.8 Conical Four-Arm Sinuous Antenna with Wideband Dual CP

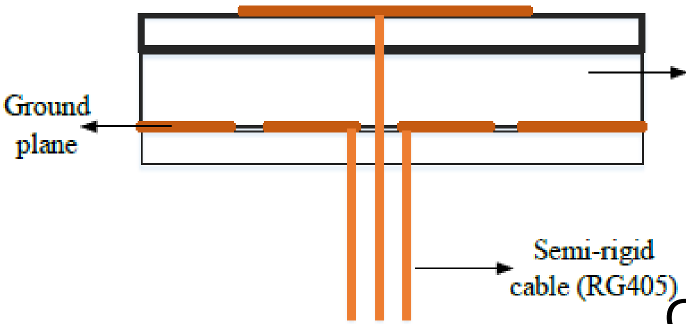


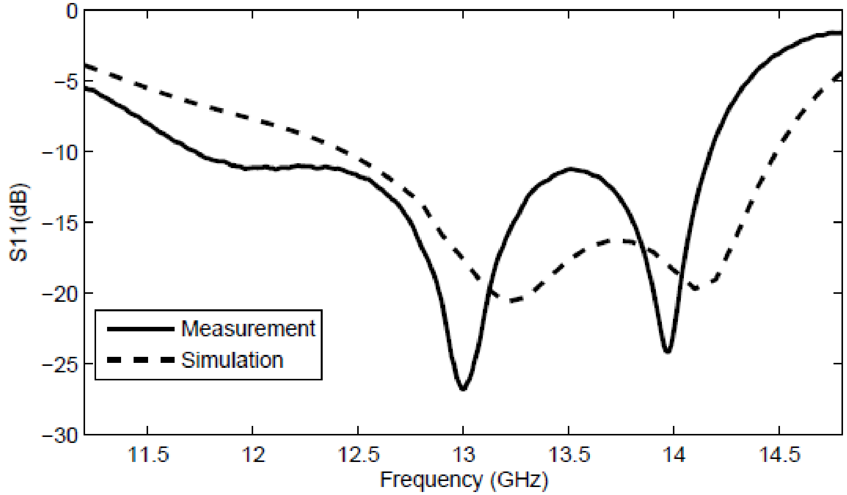


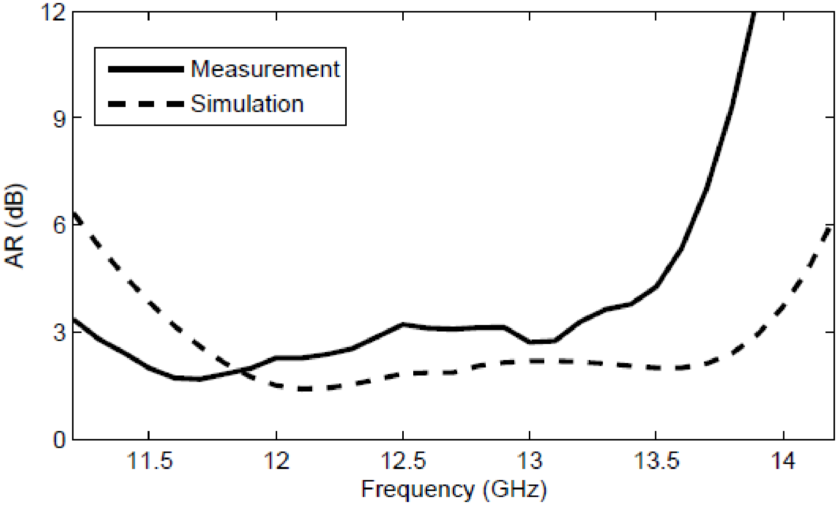
S.F. Zheng, S. Gao, Y.Z. Yin, Q. Luo, et al., A Broadband Dual Circularly Polarized Conical Four-arm Sinuous Antenna, IEEE Trans. AP, 2017, early access

2.9 Printed Monofilar Square Spiral Antenna for Small Satellites


Modified Monoifilar spiral
Feeding coaxial cable
Ground plane
RO4003C (h=0.3mm)
Rohacell@HF (ha=2mm)
RO4003C (h=0.3mm)
Z
X
Y

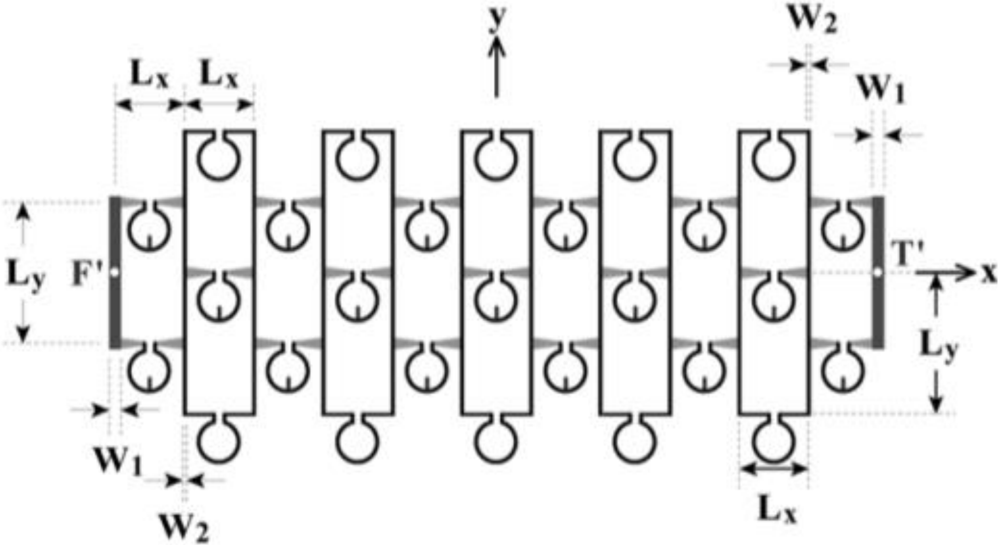

Rohacell
Ground plane
Semi-rigid cable (RG405)

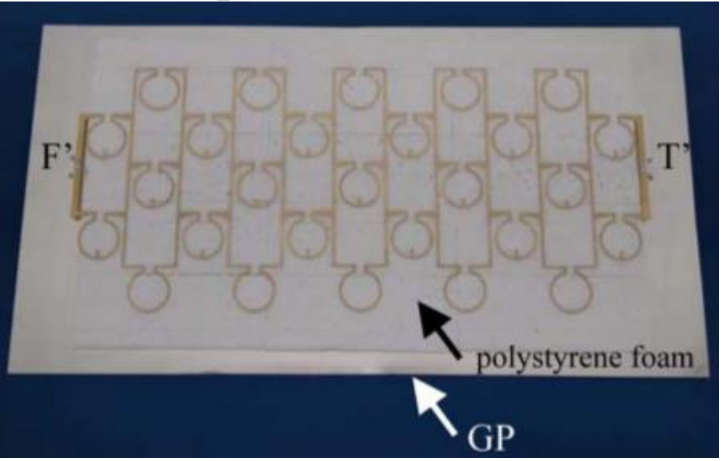


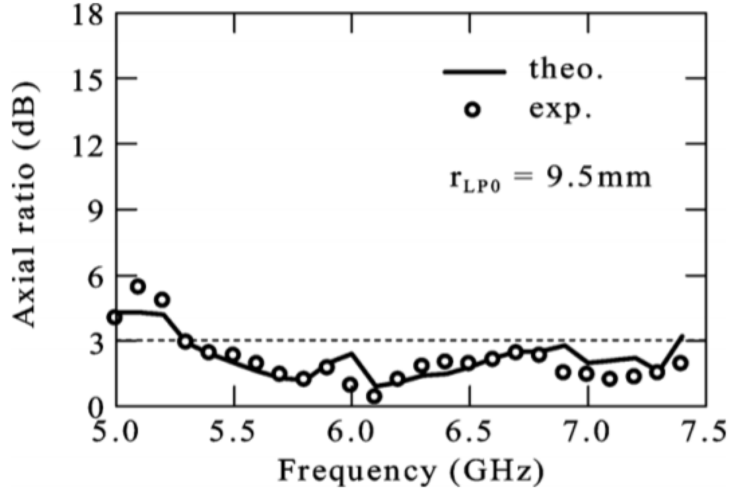


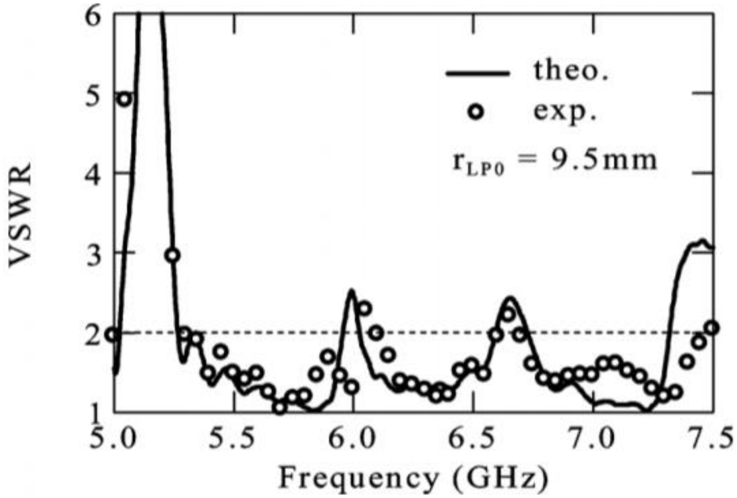
Q. Luo, S. Gao, et al., A Broadband Printed Monofilar Square Spiral Antenna : A circularly polarized low-profile antenna, IEEE Antennas and Propagation Magazine, 2017

2.10 Edge Excited CP Loop Grid Array


y
W2
Lx
Lx
W1
Ly
F'
T'
x
Ly
W1
W2
Lx

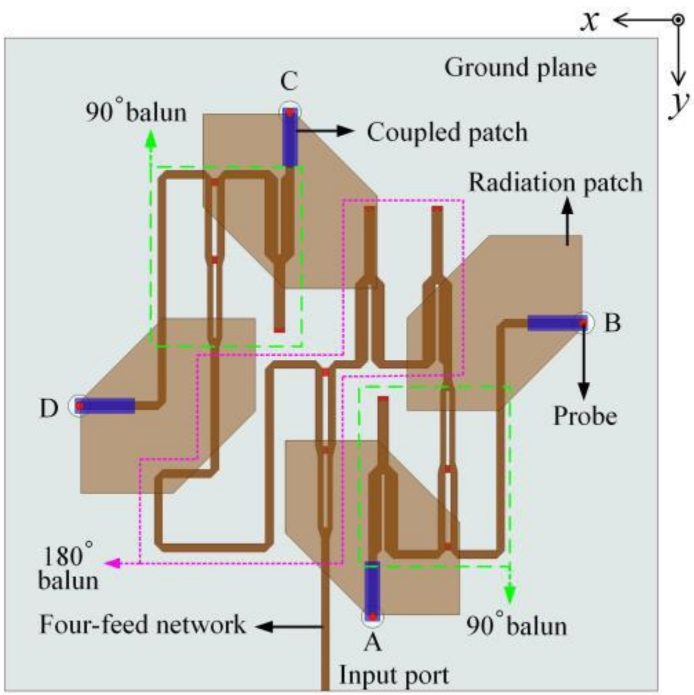

F'
T'
polystyrene foam
GP



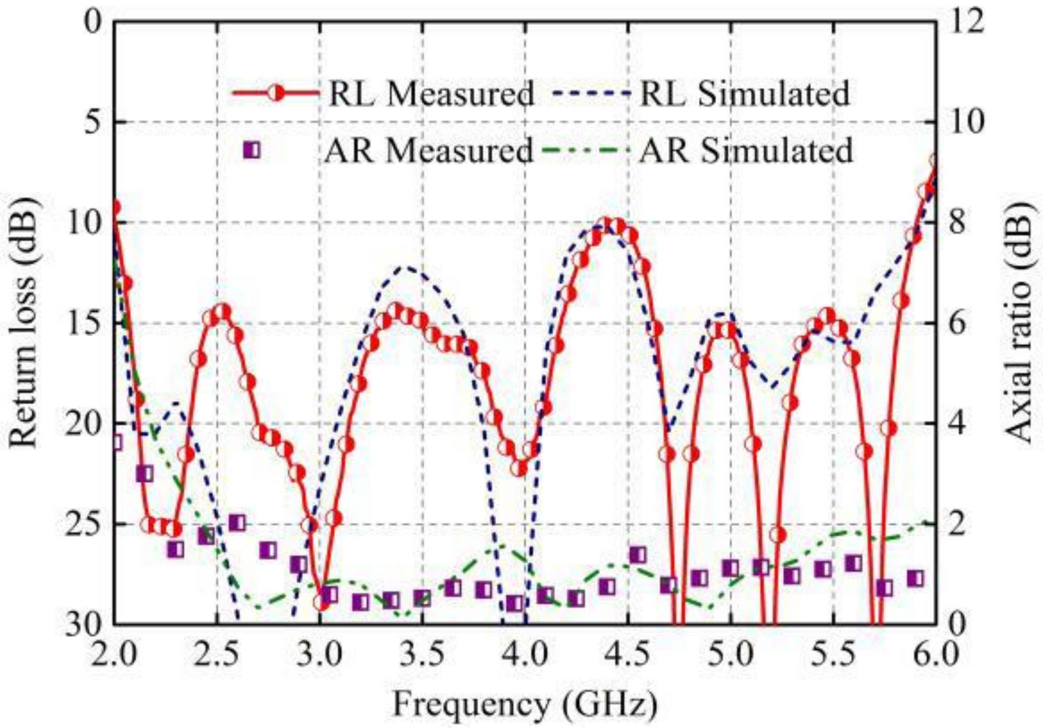


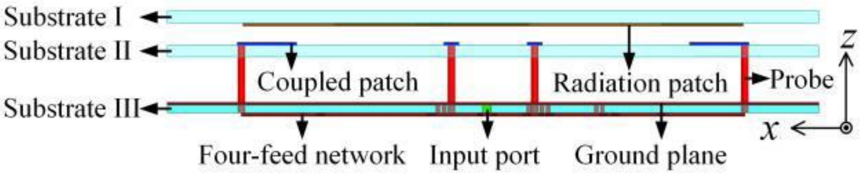
H. Nakano, Y. Iitsuka, and J. Yamauchi, Loop-based circularly polarized grid array antenna with edge excitation, IEEE Transactions on Antennas and Propagation,2013

2.11 Compact UWB Weakly Coupled Patch

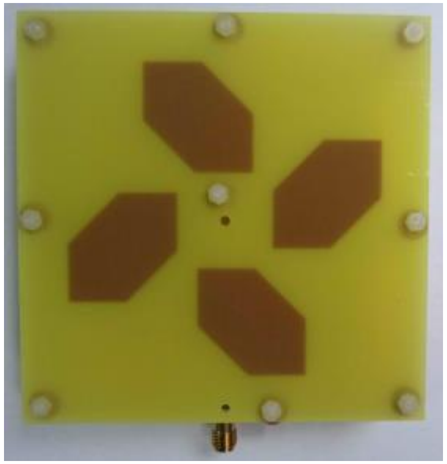

x
y
Ground plane
C
90° balun
Coupled patch
Radiation patch
B
Probe
D
180° balun
Four-feed network
A
Input port
90° balun

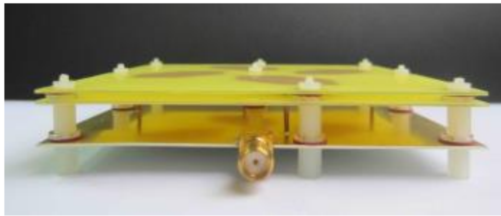
(a)




Substrate I
Substrate II
Substrate III
Coupled patch
Radiation patch
Probe
z
x
Four-feed network
Input port
Ground plane

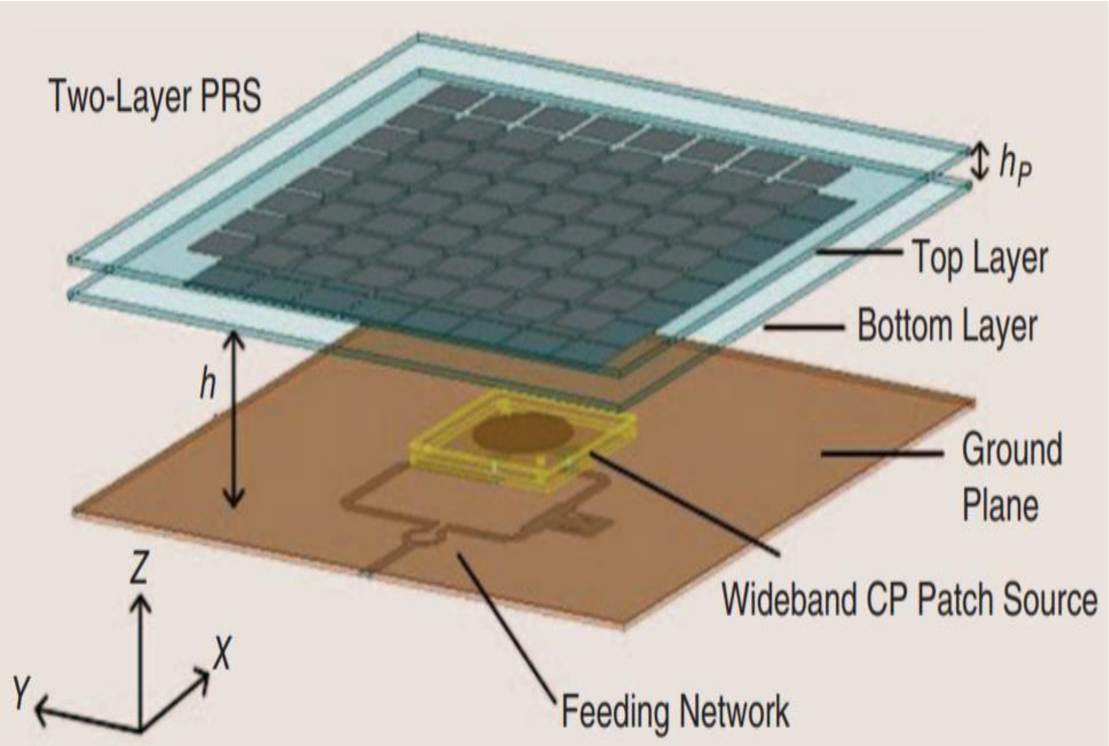
(b)

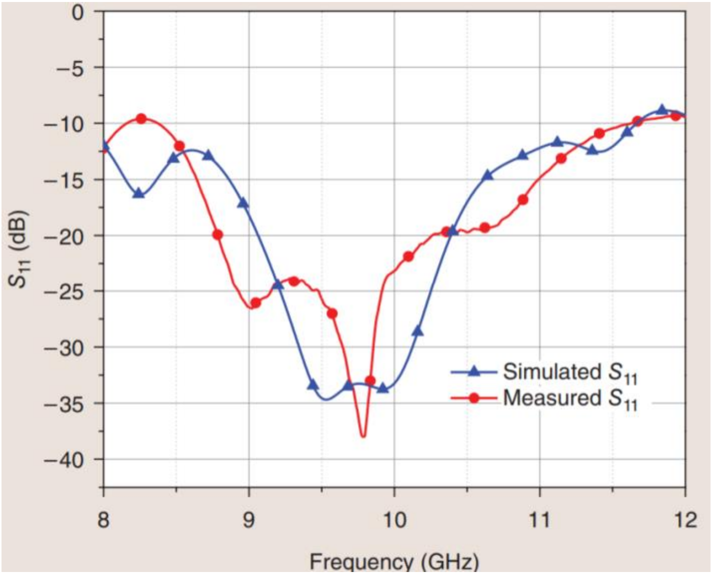


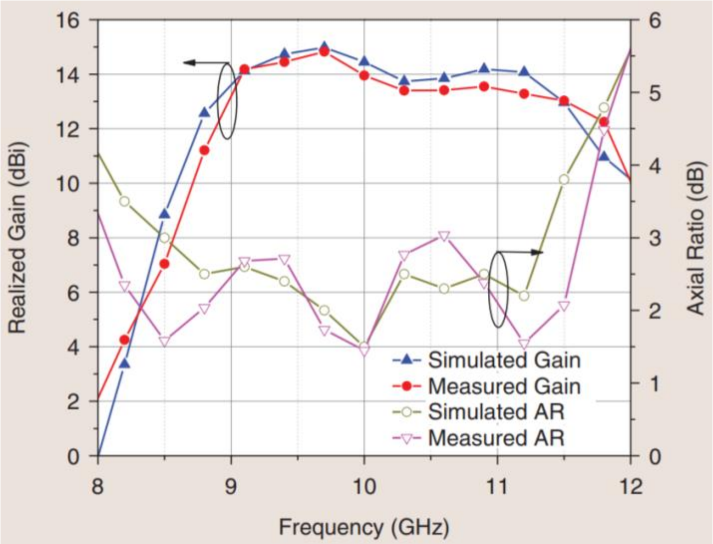


Q. Liu, Z.N. Chen, et al., Compact Ultrawideband Circularly Polarized Weakly Coupled Patch Array Antenna, IEEE Trans. AP, April 2017

2.12 Wideband CP Fabry-Perot Antenna

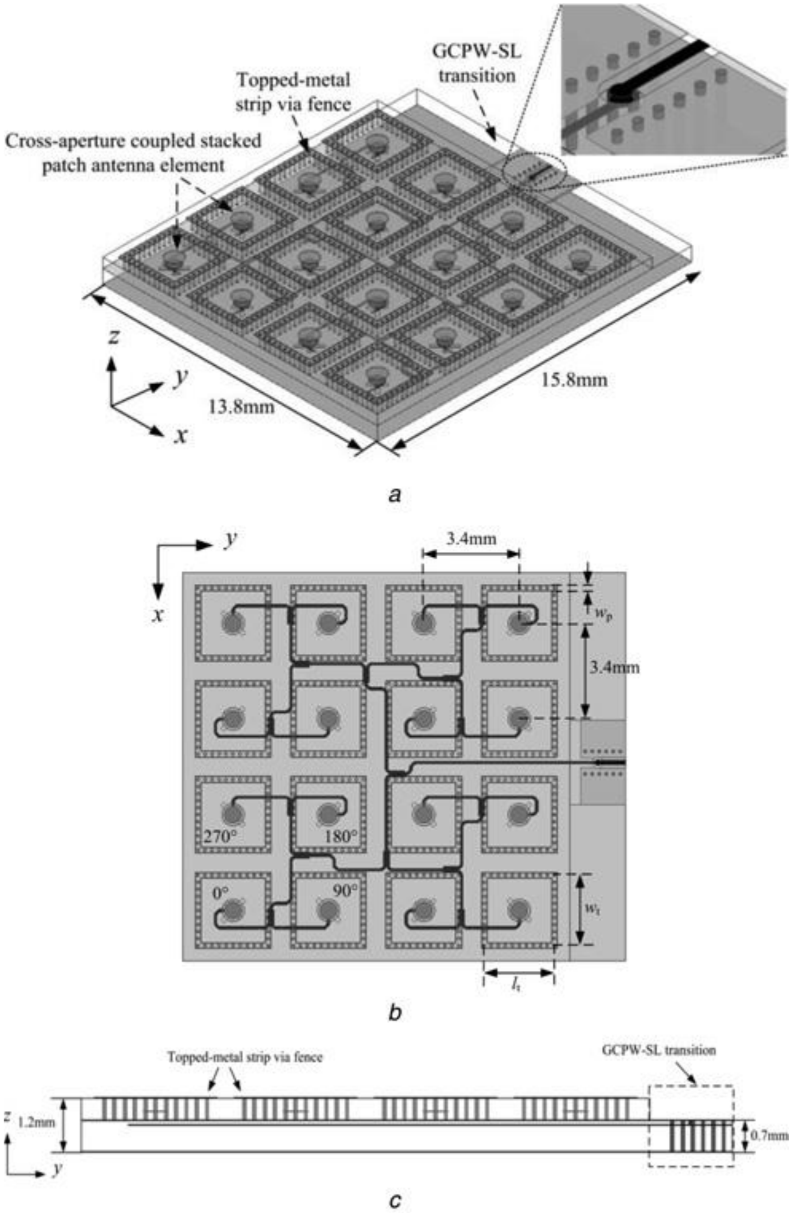

Two-Layer PRS
h_P
Top Layer
Bottom Layer
h
Ground Plane
Wideband CP Patch Source
Z
X
Y
Feeding Network

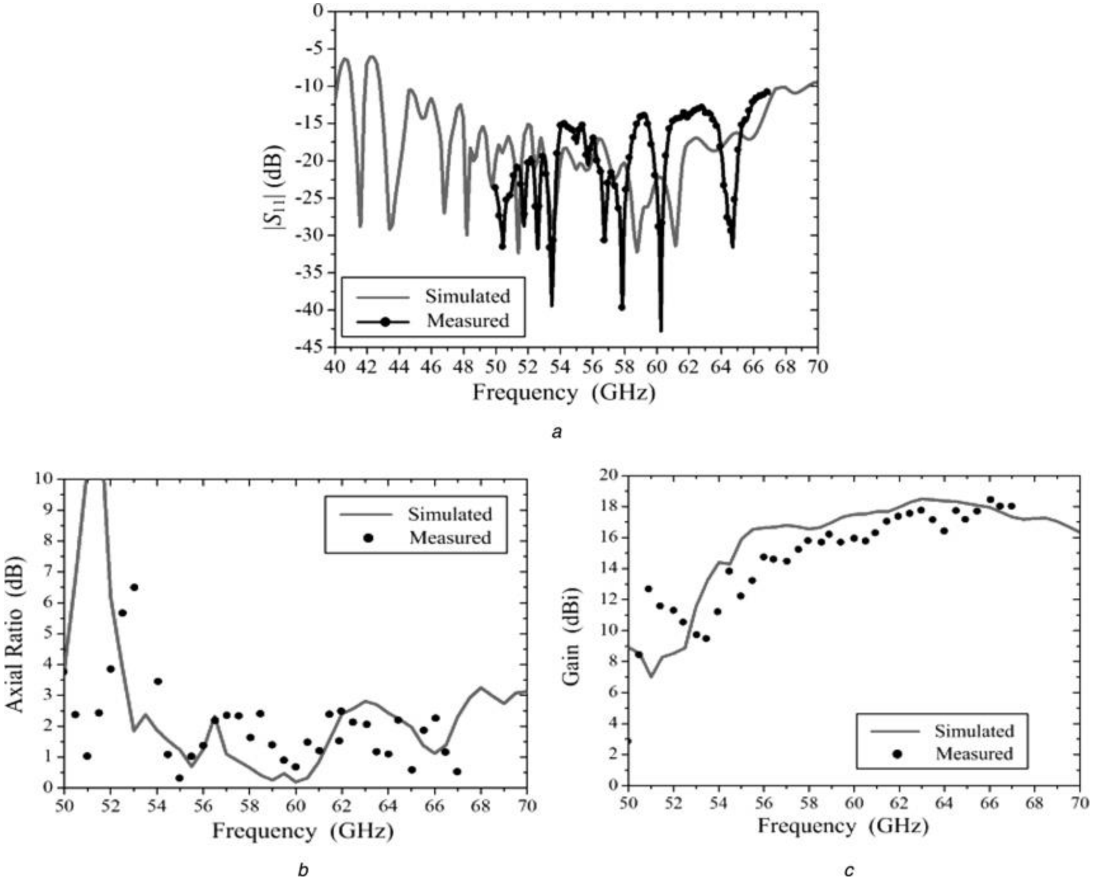




F. Qin, S. Gao, Q. Luo, et al, Wideband Circularly Polarized Fabry-Perot Antenna, IEEE Antennas Propagation Magazine, 2015, pp. 127-135

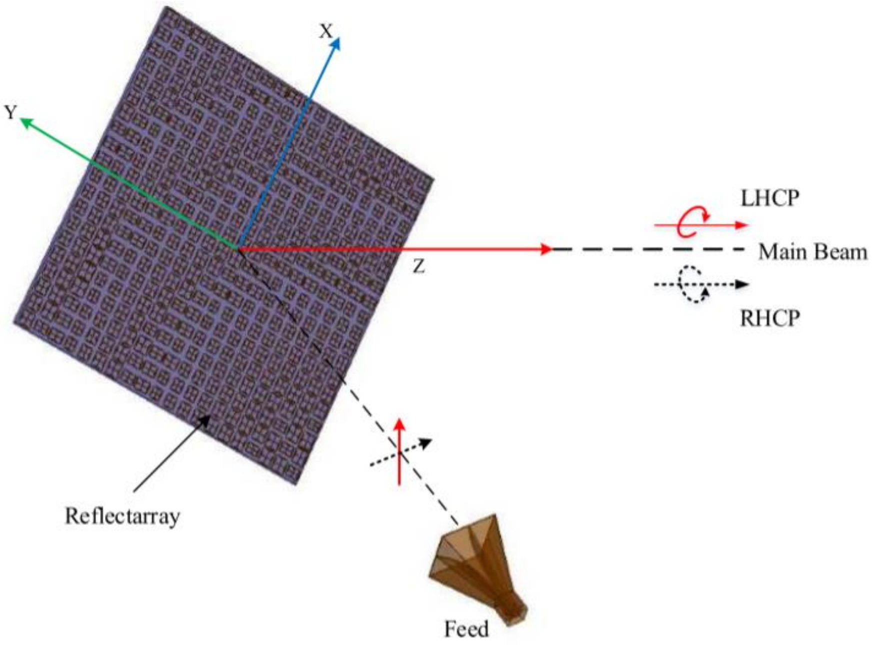
2.13 Wideband 60-GHz CP Patch Array in LTCC

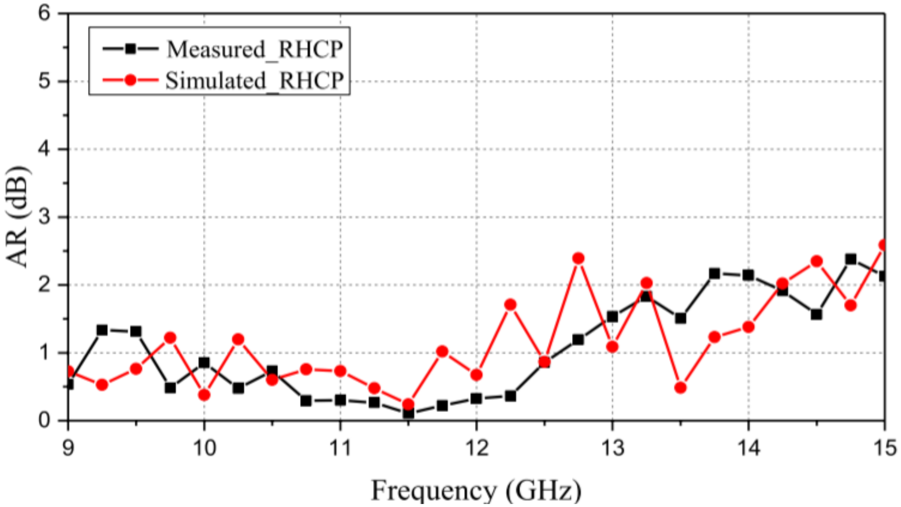

GCPW-SL transition
Topped-metal strip via fence
Cross-aperture coupled stacked patch antenna element
z
y
x
13.8mm
15.8mm
a
y
x
3.4mm
w_p
3.4mm
270°
180°
0°
90°
w_t
l_t
b
Topped-metal strip via fence
GCPW-SL transition
z
1.2mm
y
0.7mm
c

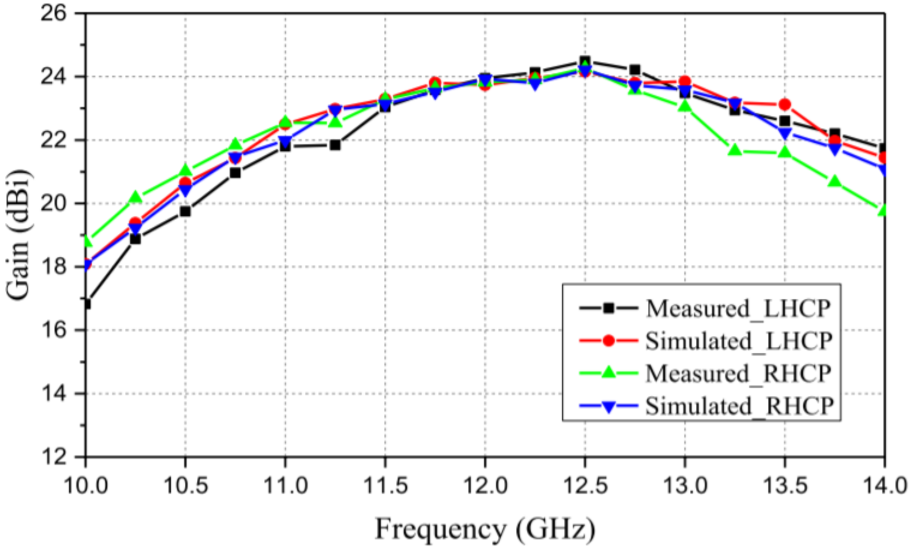


L. Wang, Y.X. Guo, W. Wu, Wideband 60 GHz circularly polarised stacked patch antenna array in low-temperature co-fired ceramic technology, IET MAP, 2015

2.14 Wideband CP Reflectarray

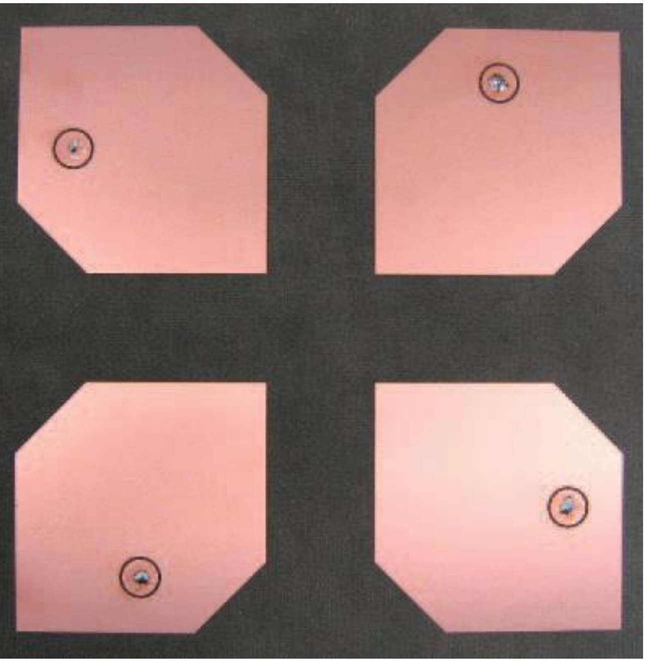

X
Y
Z
LHCP
Main Beam
RHCP
Reflectarray
Feed

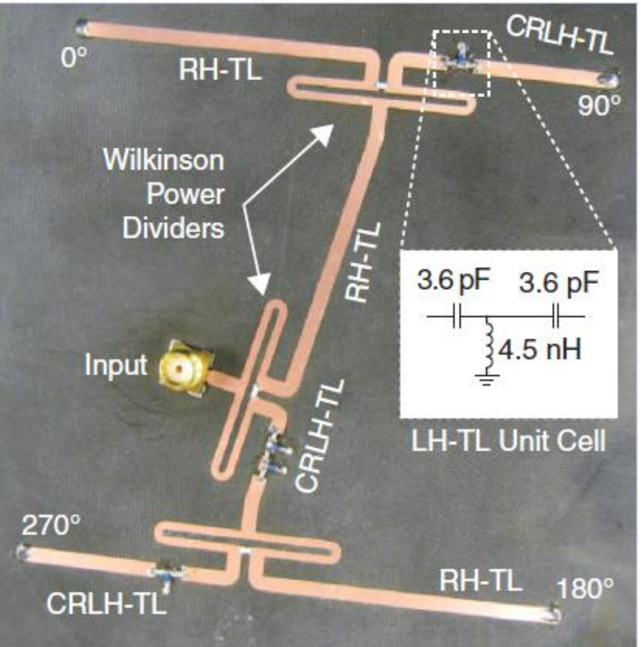


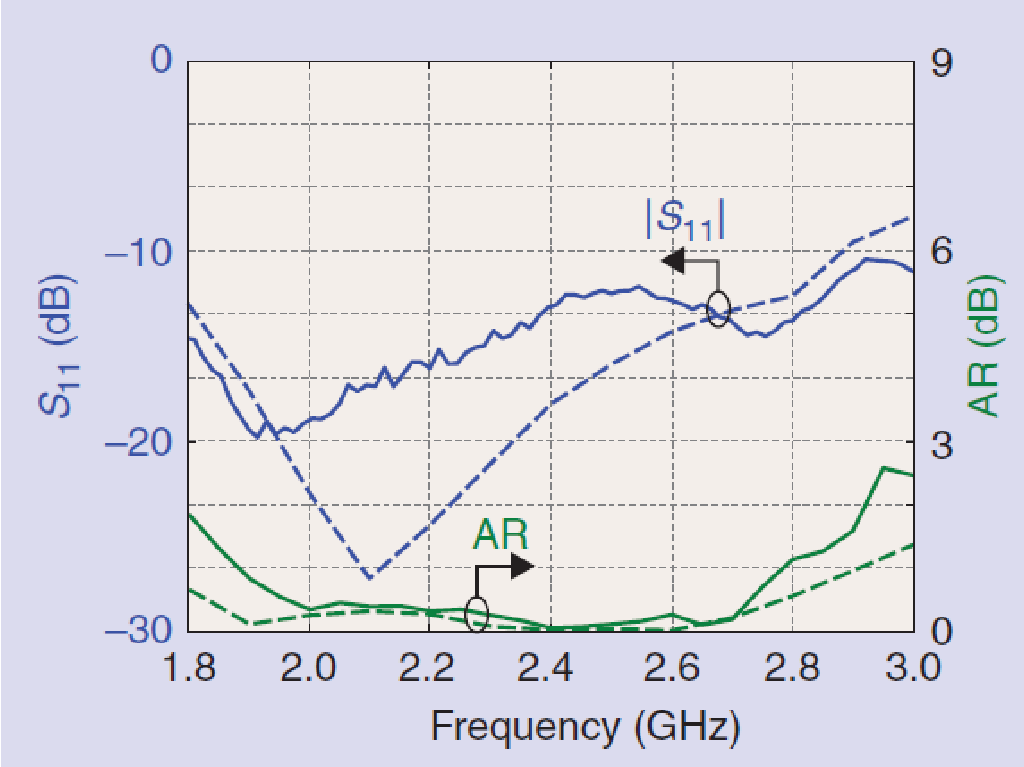


G. Wu, S.-W. Qu, S.W. Yang, and C. H. Chan, Broadband, Single-Layer Dual Circularly Polarized Reflectarrays With Linearly Polarized Feed, IEEE Trans. on Antennas and Propagat., 2016

2.15 Wideband CP Arrays Using Metamaterial

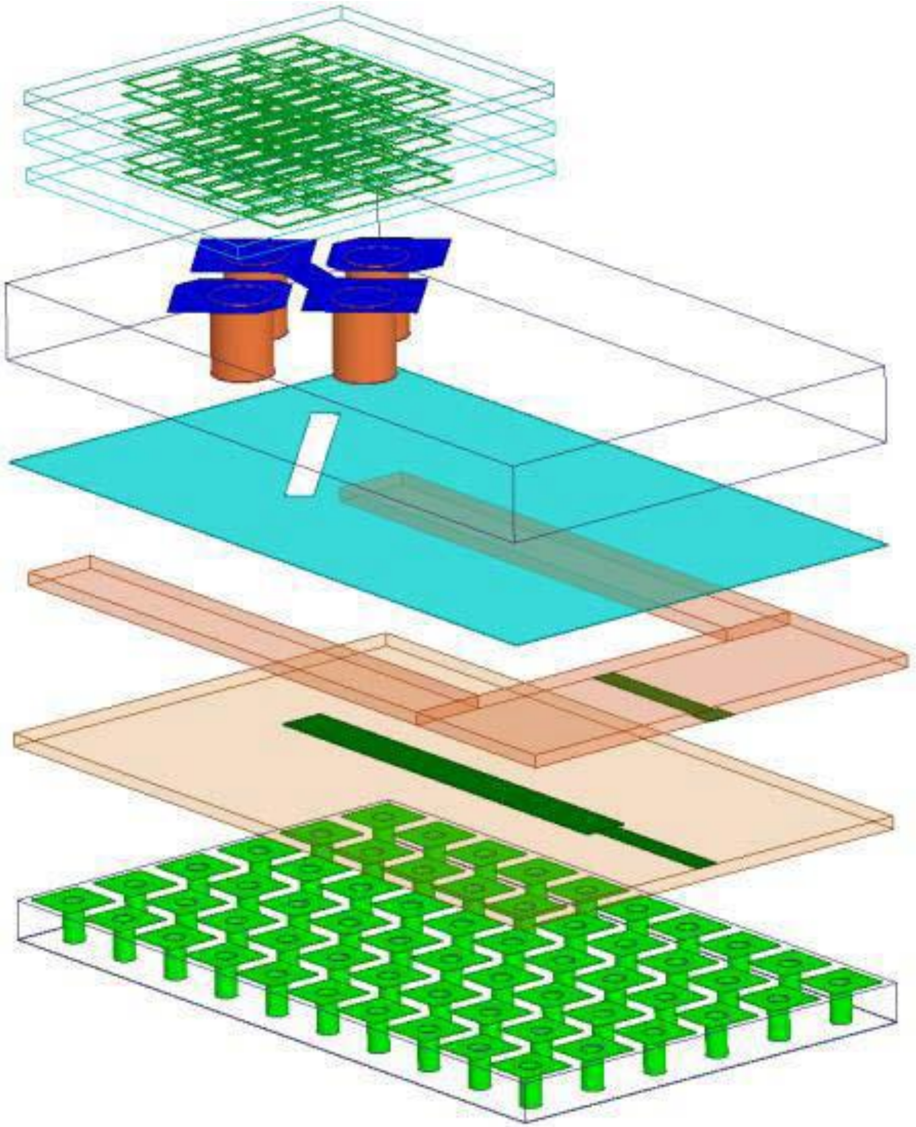


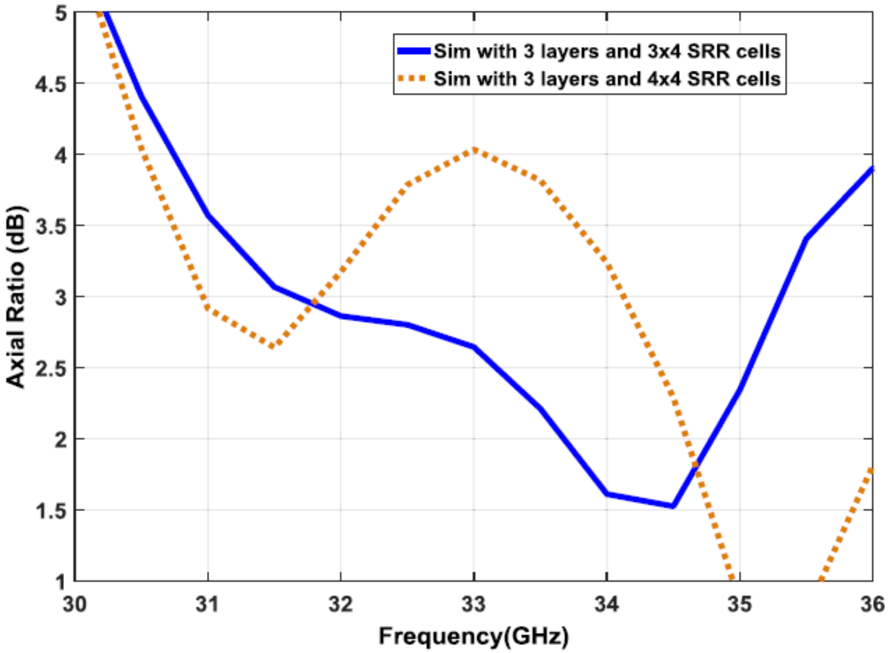

0°
RH-TL
CRLH-TL
90°
Wilkinson
Power
Dividers
RH-TL
3.6 pF
3.6 pF
4.5 nH
LH-TL Unit Cell
Input
CRLH-TL
270°
CRLH-TL
RH-TL
180°



J.M. Kovitz. J. Choi, Y. Rahmat-Samii, Supporting Wide-Band Circular Polarization: CRLH Networks for High-Performance CP Antenna Arrays, IEEE Microwave Magazine, 2017

2.16 Broadband High-Efficiency CP ME Antenna Using Printed Ridge Gap Waveguide



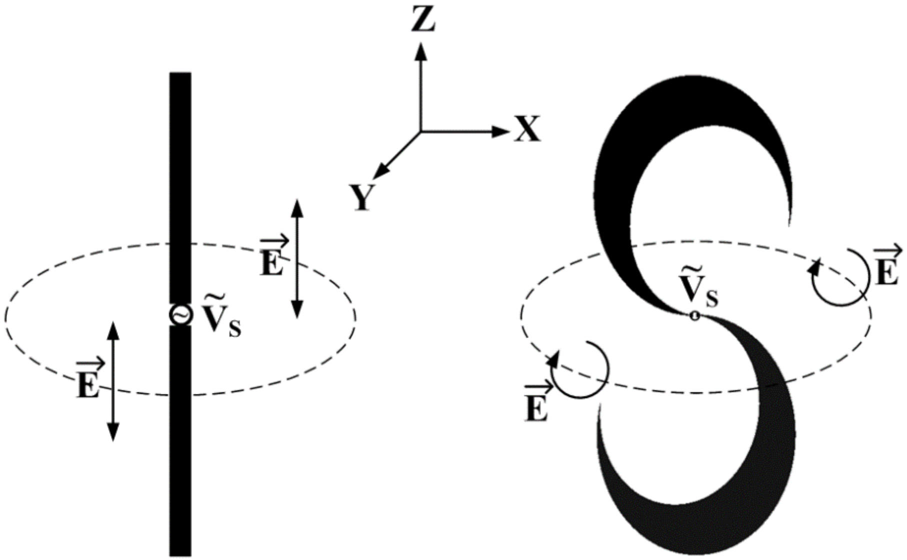

Sim with 3 layers and 3x4 SRR cells
Sim with 3 layers and 4x4 SRR cells
Axial Ratio (dB)
5
4.5
4
3.5
3
2.5
2
1.5
1
30
31
32
33
34
35
36
Frequency(GHz)

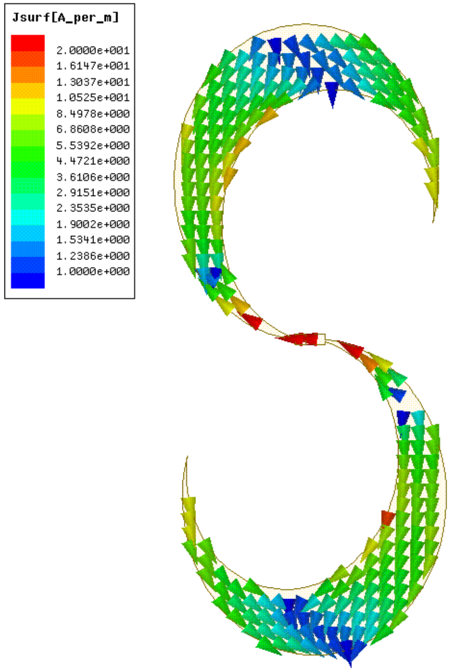
A. Dadgarpour, M. Sorkherizi and A.A. Kishk, High-Efficient Circularly Polarized Magnetoelectric Dipole Antenna for 5G Applications Using Dual-Polarized Split-Ring Resonator Lens, IEEE Trans. AP, 2017

3. Case Studies of Wideband CP Antennas

3.1 Wideband CP antennas using inverted-S element

Wideband CP inverted-S antenna

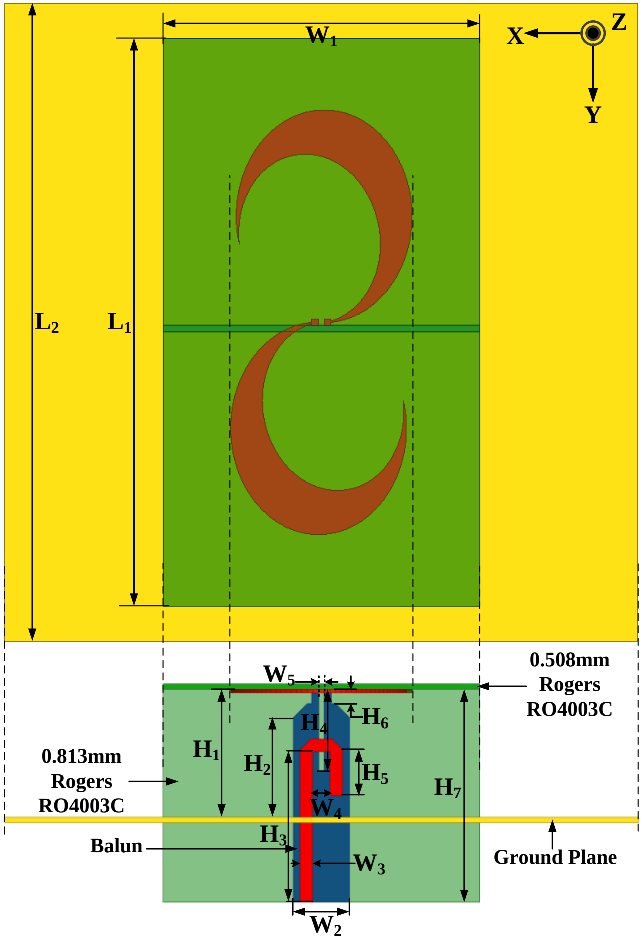

Z
X
Y
$\vec{E}$
$\tilde{V}_S$
$\vec{E}$
$\tilde{V}_S$
$\vec{E}$
$\vec{E}$

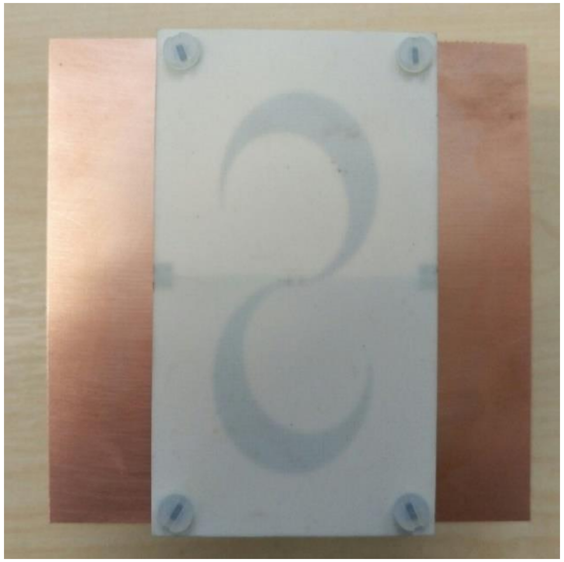


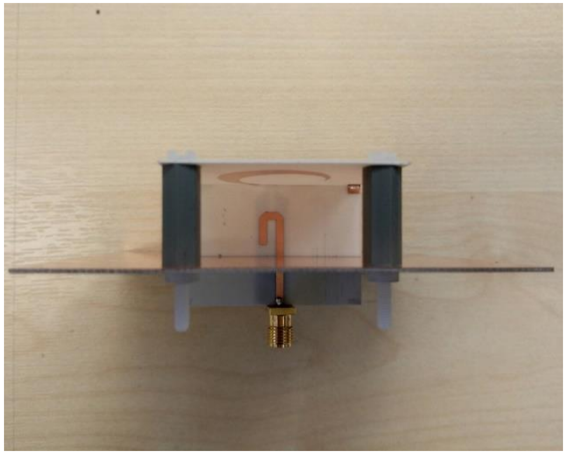
Linearly polarized dipole to CP inverted-S dipole

Animation of travelling-wave surface current

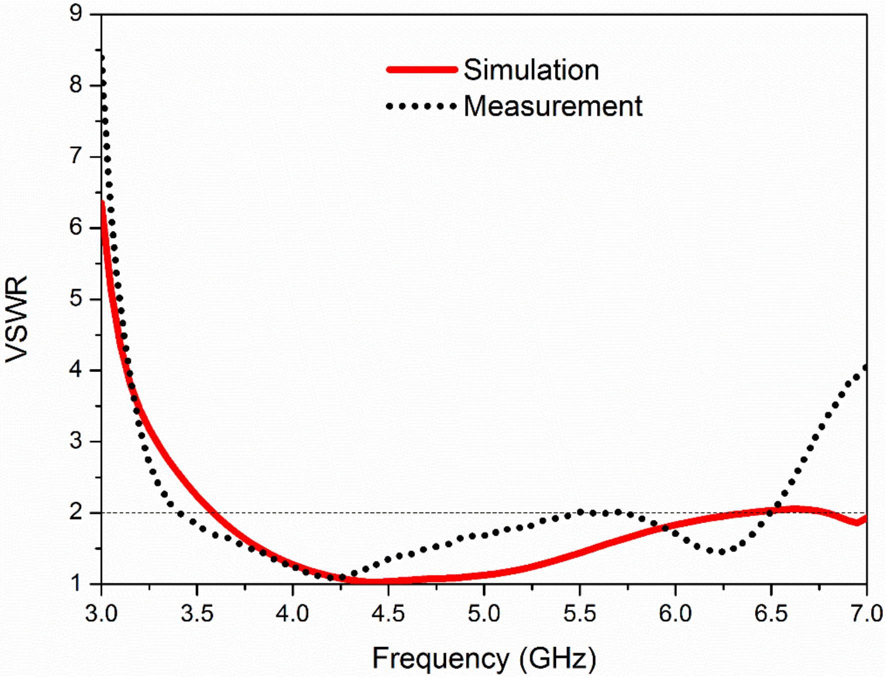
Wideband CP inverted-S antenna

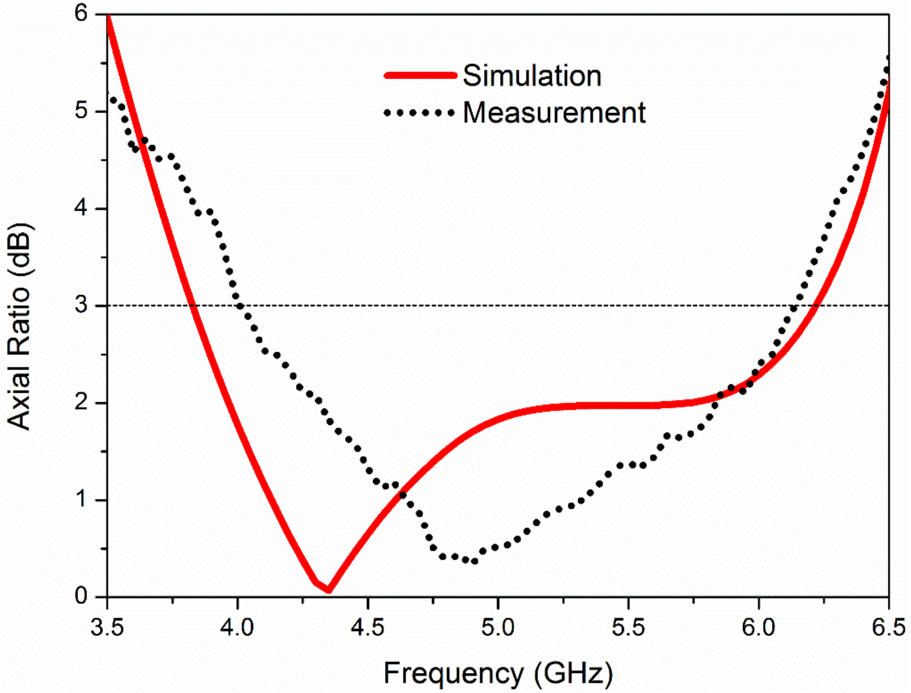

W$_1$
X
Z
Y
L$_2$
L$_1$
W$_5$
0.508mm
Rogers
RO4003C
H$_4$
H$_6$
H$_1$
H$_2$
H$_5$
H$_7$
0.813mm
Rogers
RO4003C
W$_4$
H$_3$
Balun
W$_3$
Ground Plane
W$_2$





L. Zhang, S. Gao, Q. Luo, P. Young, Q. Li, Inverted-S Antenna with Wideband Circular Polarization and Wide Axial Ratio Beamwidth, *IEEE Trans. on AP*, April 2017, pp. 1740-1749

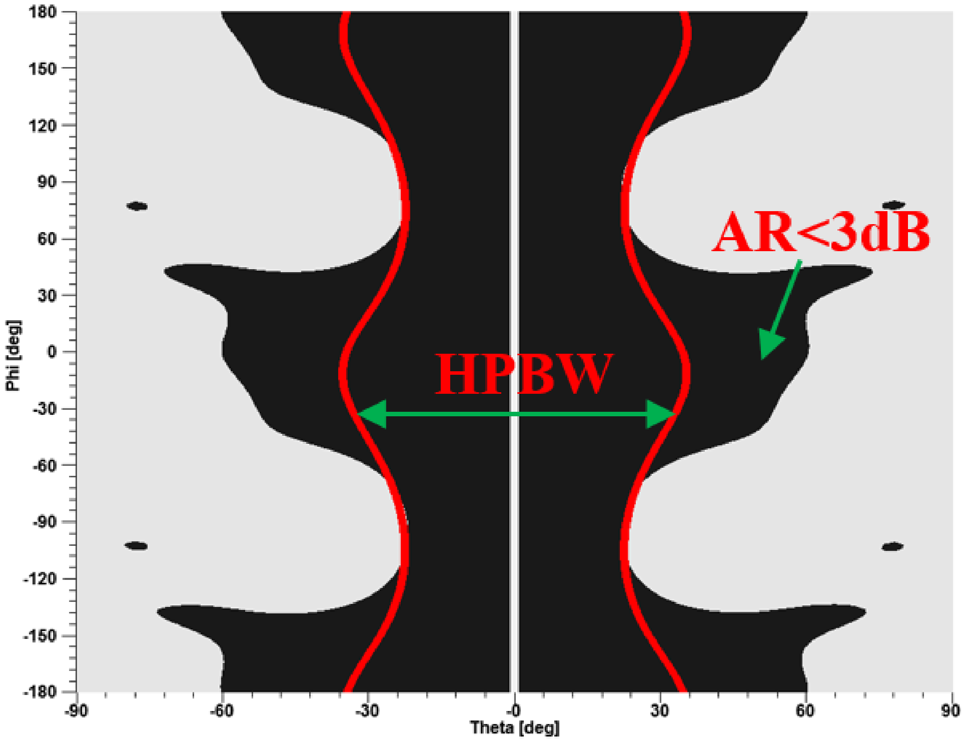


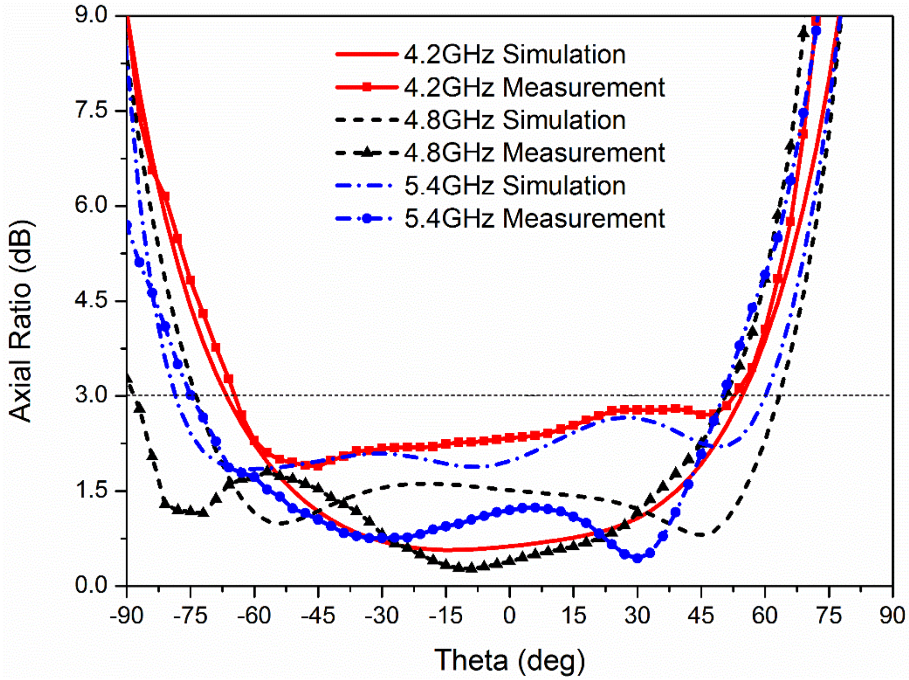


VSWR<2 bandwidth: 63%

AR<3dB bandwidth: 42%

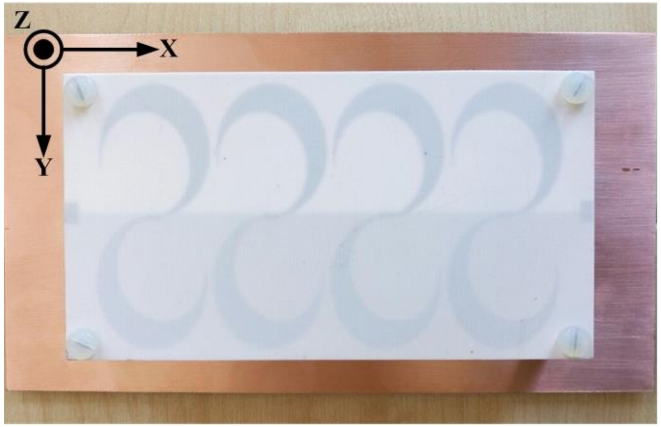
University of Kent

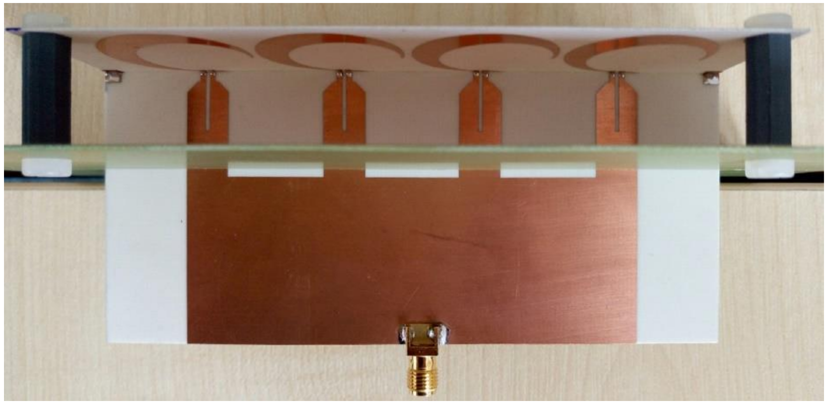


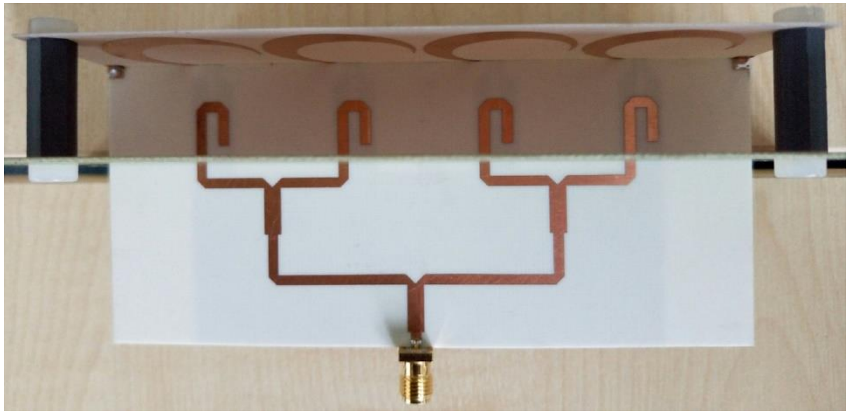


The 3-dB AR beamwidth can cover the HPBW in the whole upper hemisphere

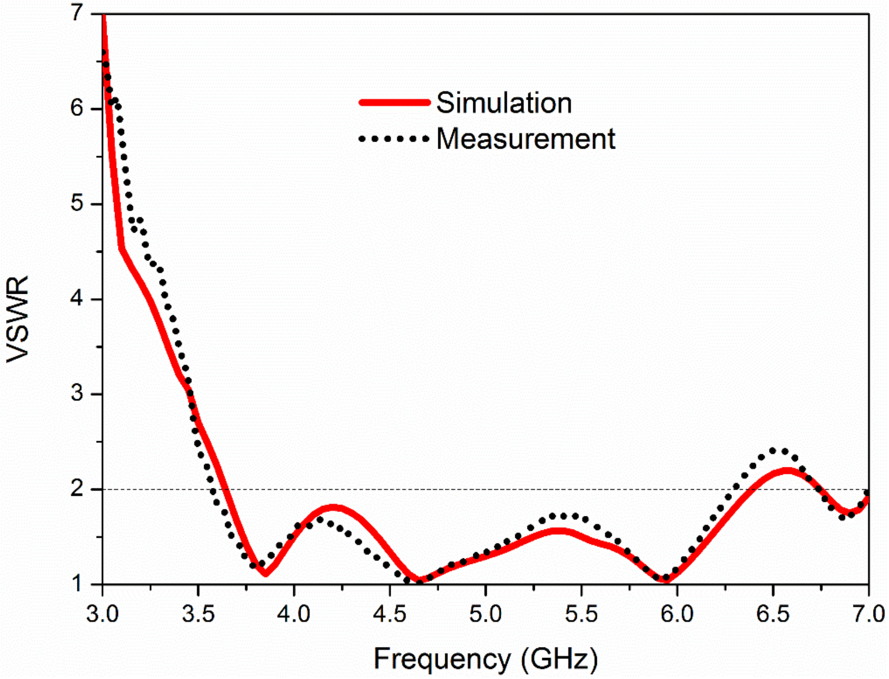
Extend to linear arrays

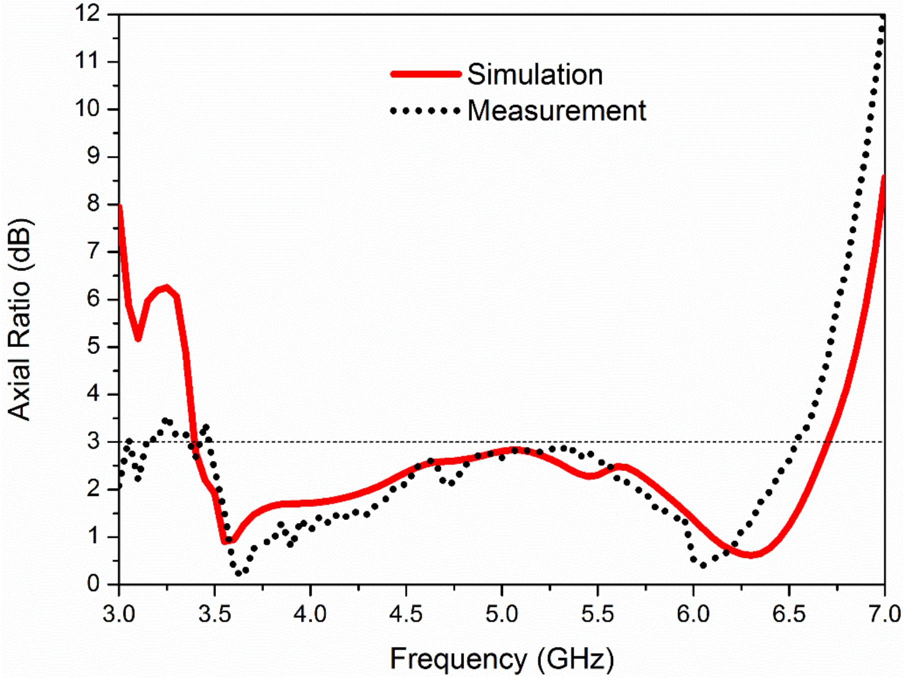






- Bandwidth of the linear array



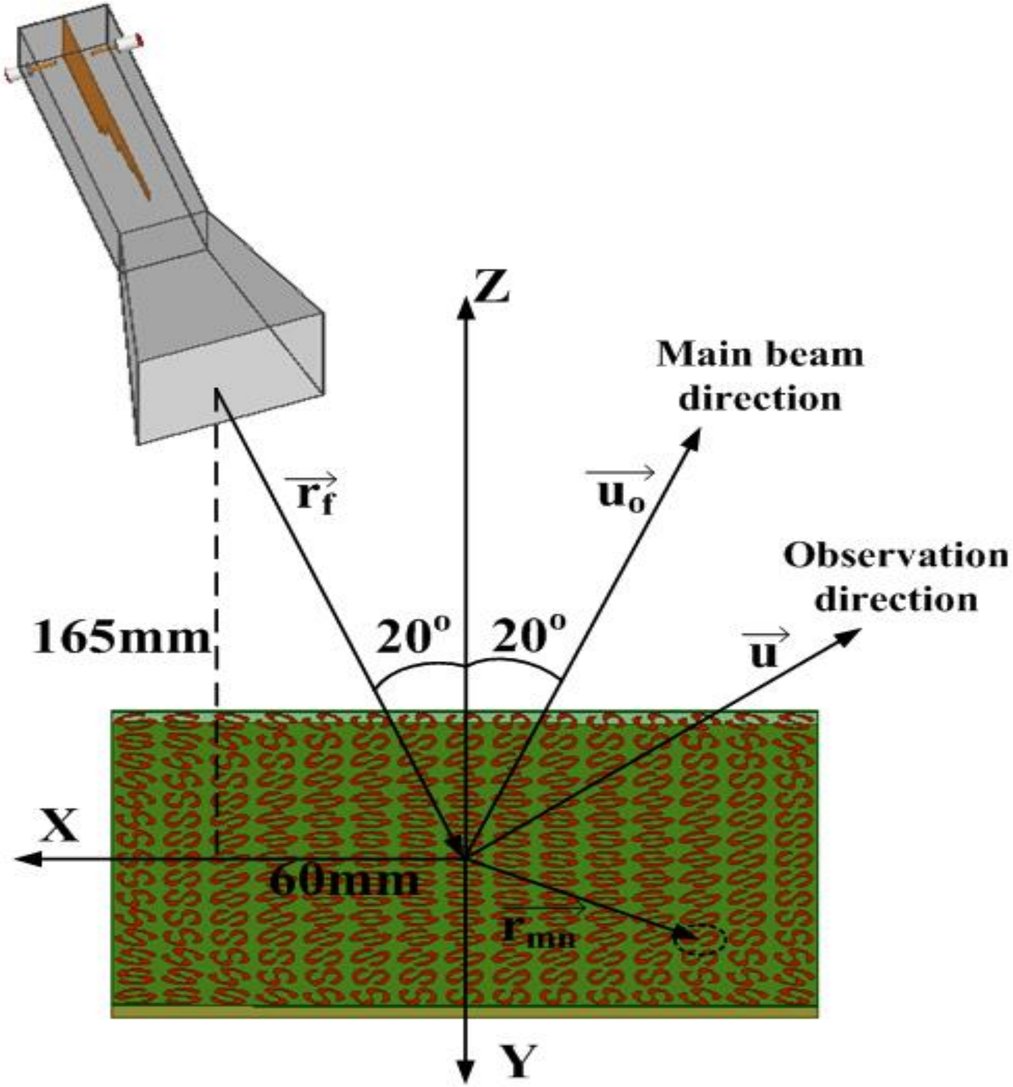


VSWR<2 bandwidth: 55.3%

AR<3dB bandwidth: 60%

3.2 Single-Layer Wideband CP High-Efficiency Reflectarrays

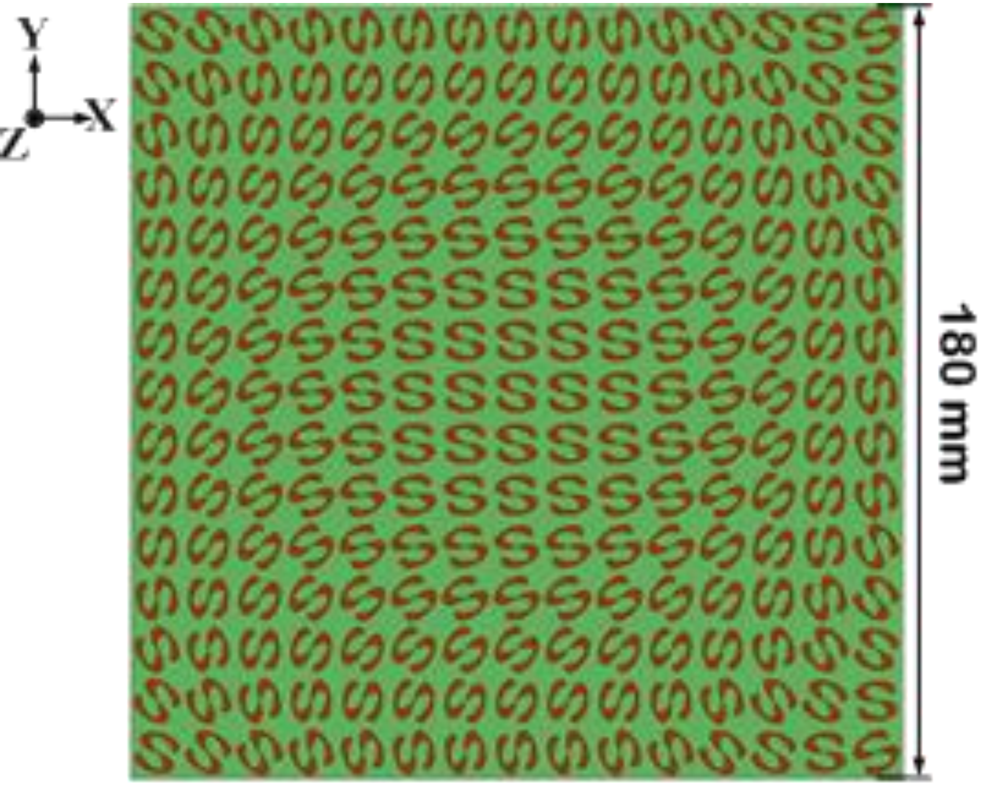
Single-layer wideband CP high-efficiency reflectarray

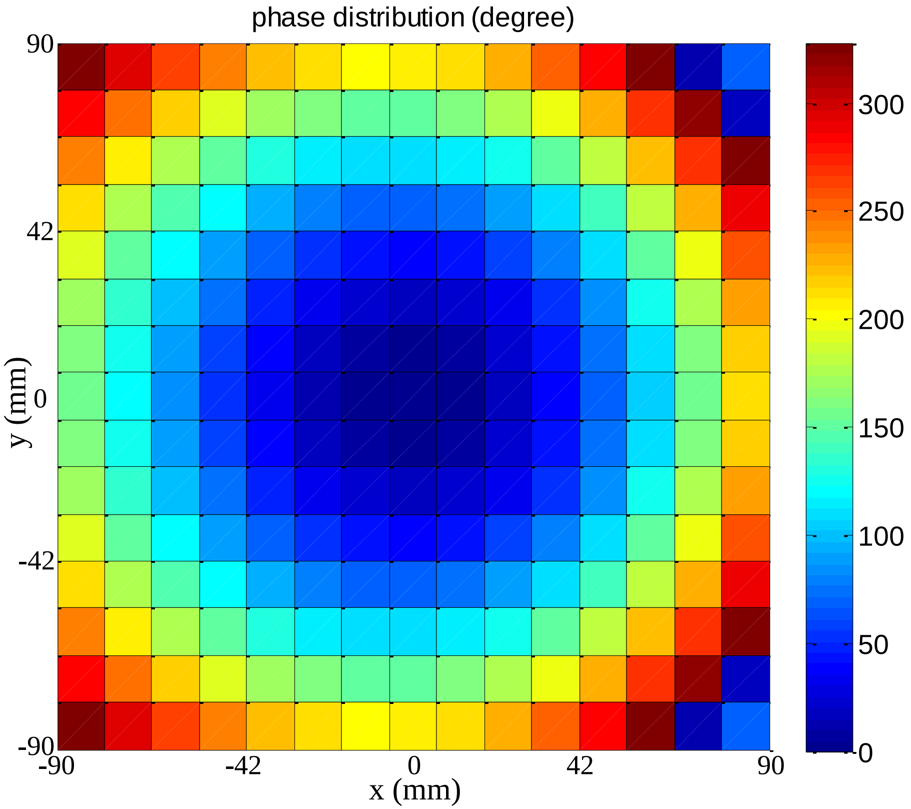

Z
Main beam direction
$\vec{u_o}$
$\vec{r_f}$
Observation direction
$\vec{u}$
165mm
20°
20°
X
60mm
$\vec{r_{mn}}$
Y

- Single layer;
- S-shaped elements are employed in the reflectarray

L. Zhang, S. Gao, Q. Luo, P. Young, Q. Li, Single-Layer Wideband Circularly Polarized High-Efficiency Reflectarray for Satellite Communications, *IEEE Trans. on AP*, September 2017, pp. 4529 - 4538

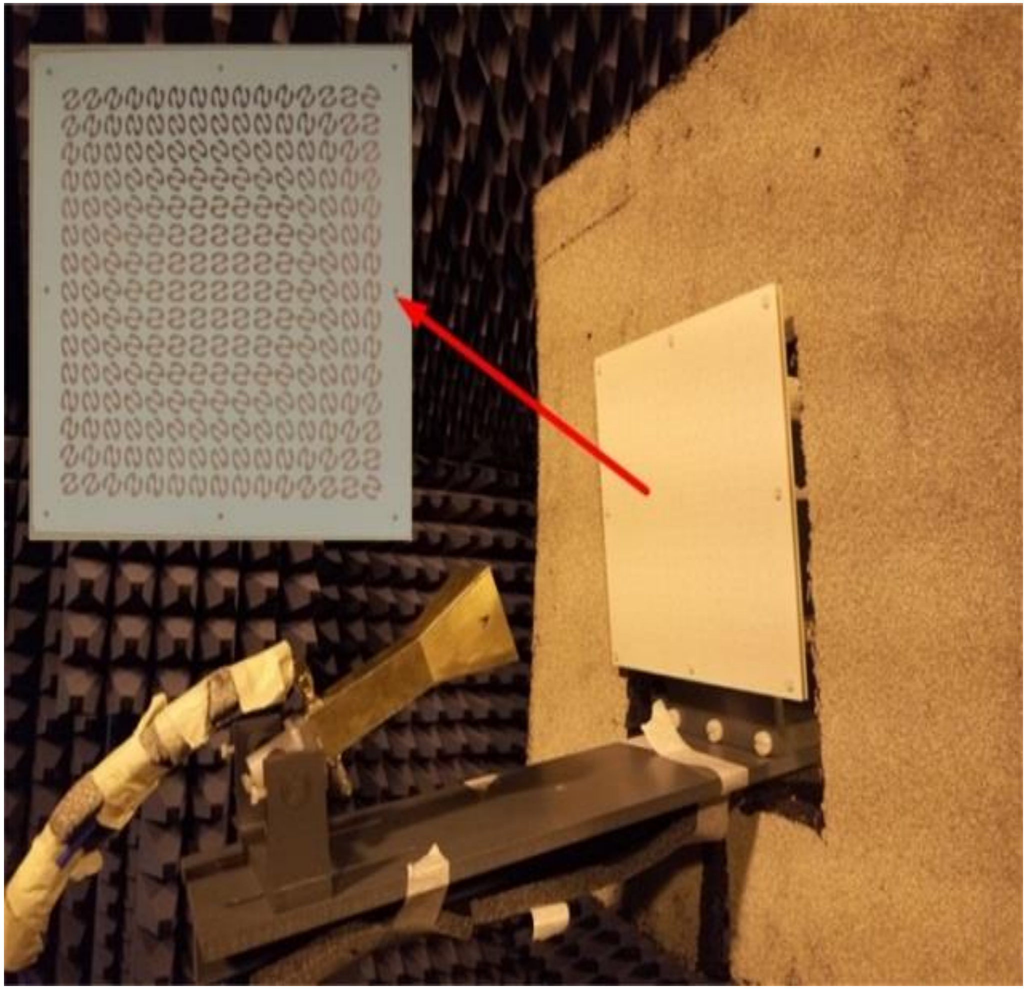
Reflectarray and phase distribution of each element

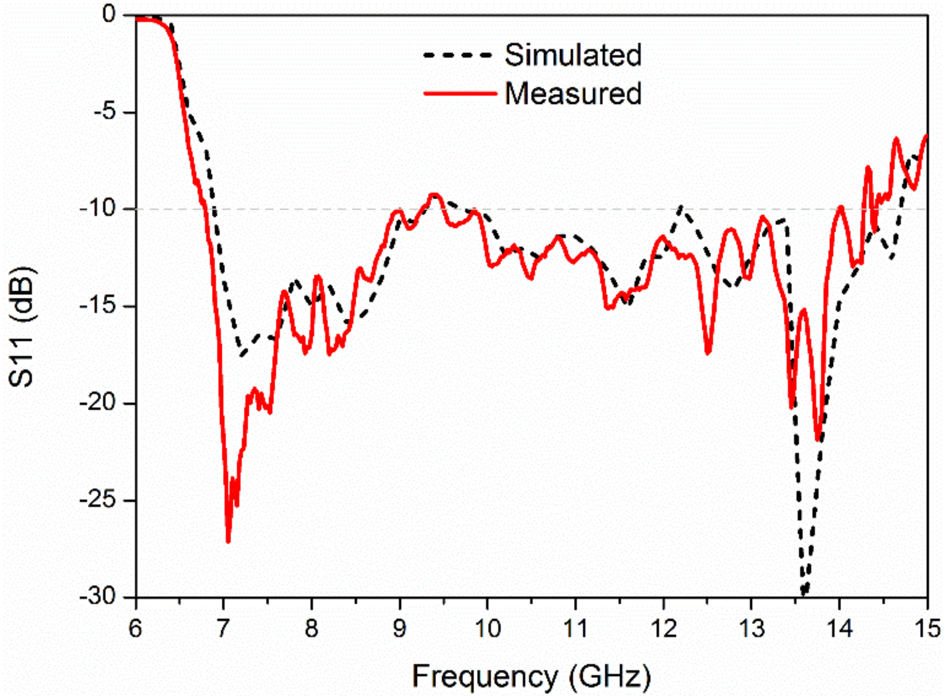


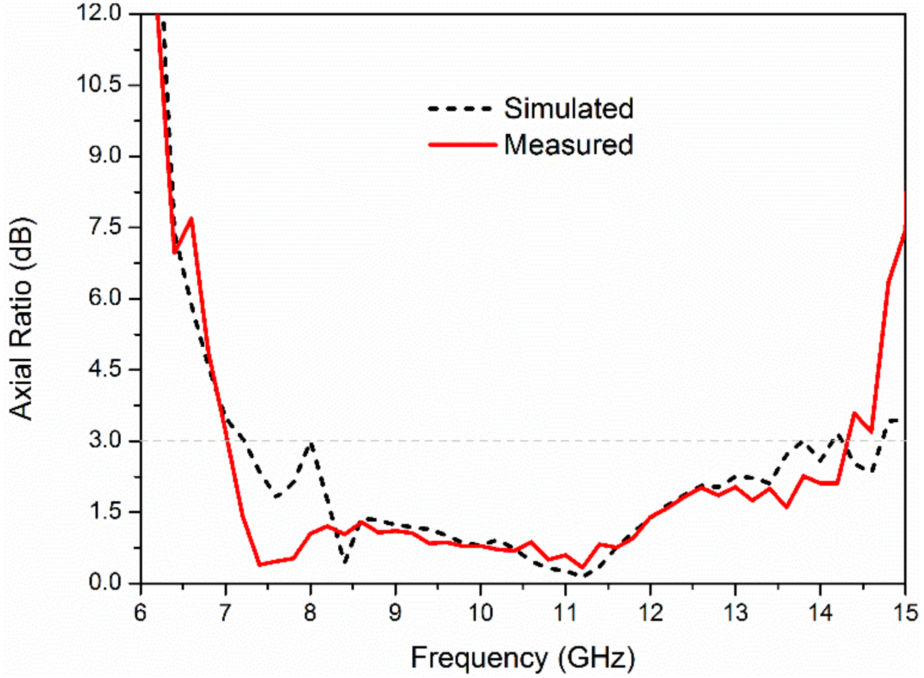


$$\boldsymbol{\Phi(x_i, y_i)}$$
$$\boldsymbol{= -k_0\, sin\, \theta_b (\, x_i\, cos\, \varphi_b + y_i \sin \varphi_b)}$$
$$\boldsymbol{+ R_i k_0}$$

Photo of the reflectarray in our laboratory

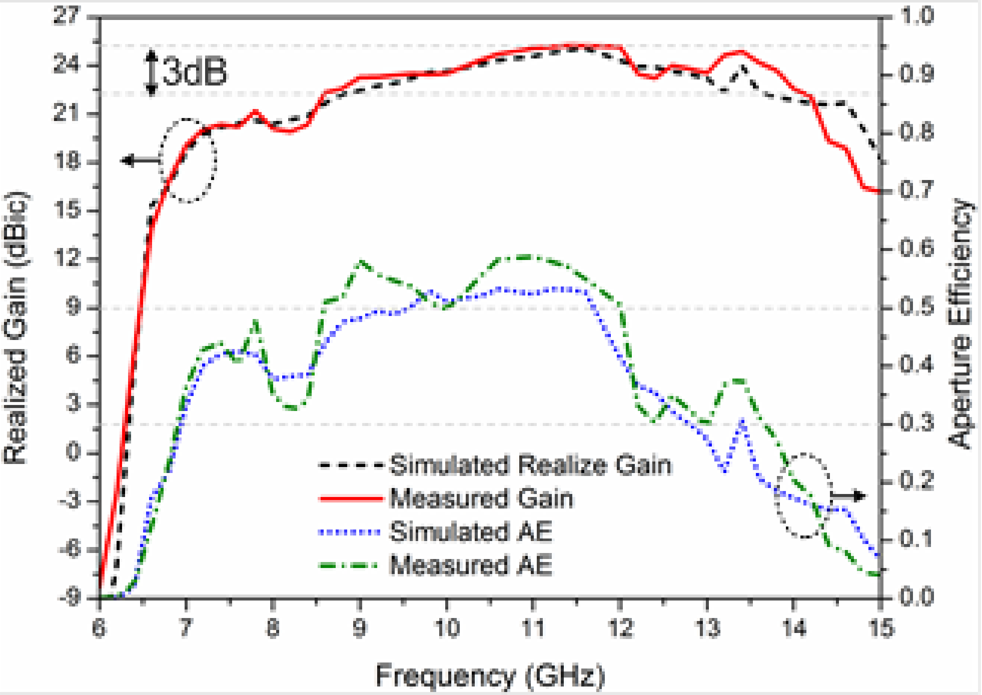


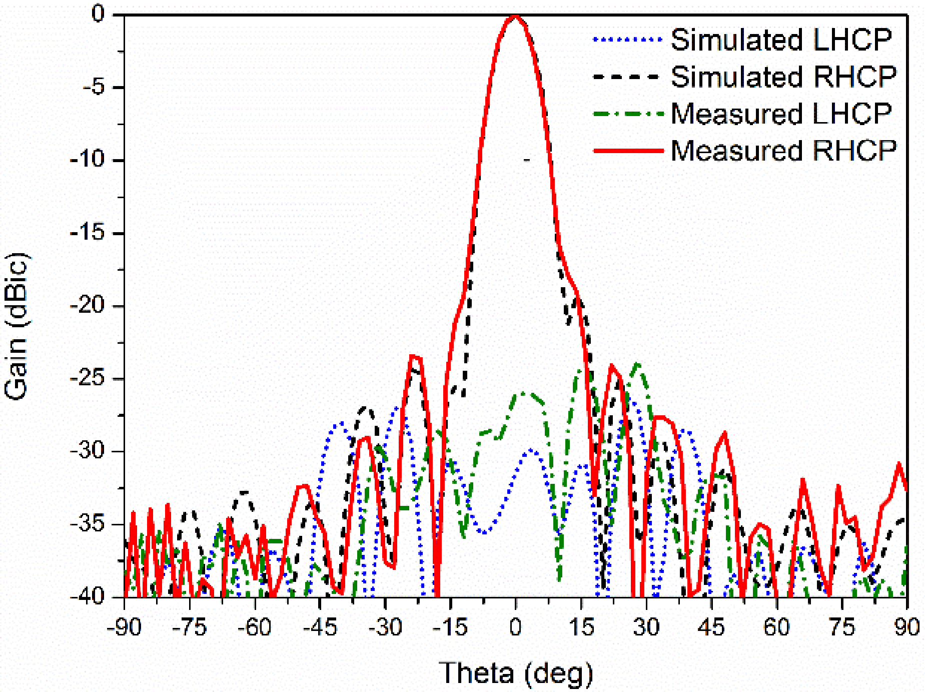




S11<-10dB bandwidth: 7.0-14.2GHz

AR<3dB bandwidth: 7.0-14.3GHz





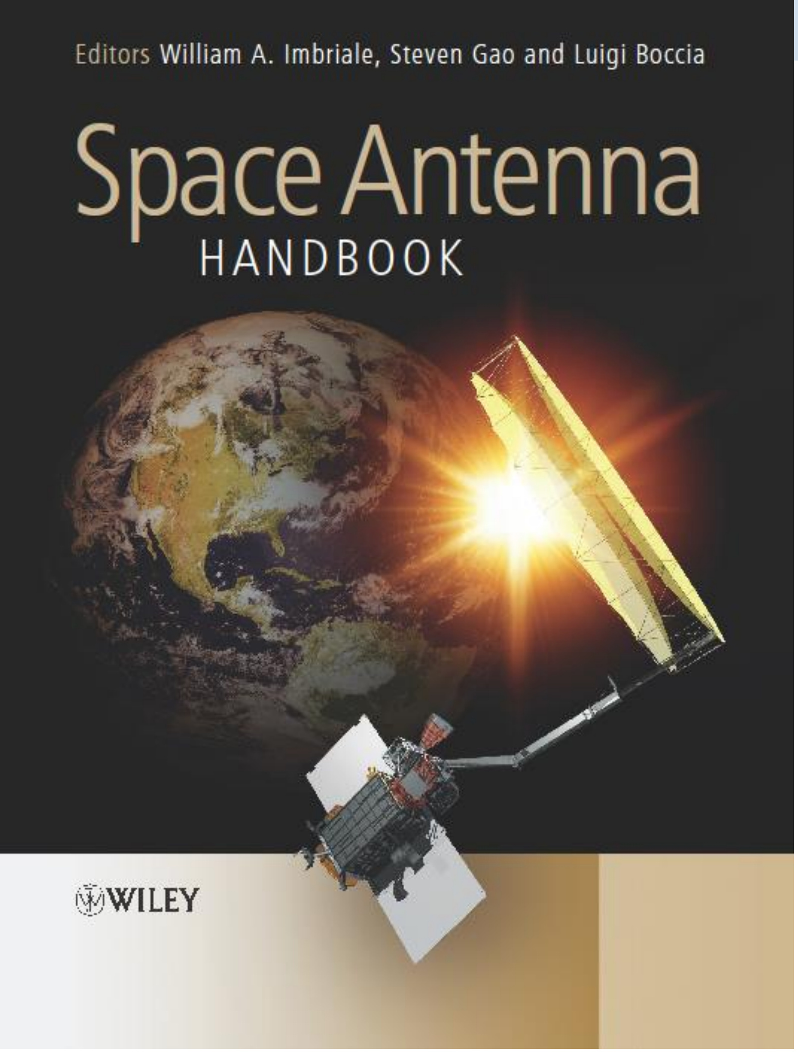
3dB gain bandwidth: 8.6-14 GHz

Aperture efficiency >50% over the range from 8.6 GHz to 12.0 GHz

Radiation Pattern at 10.6 GHz

4. Conclusions

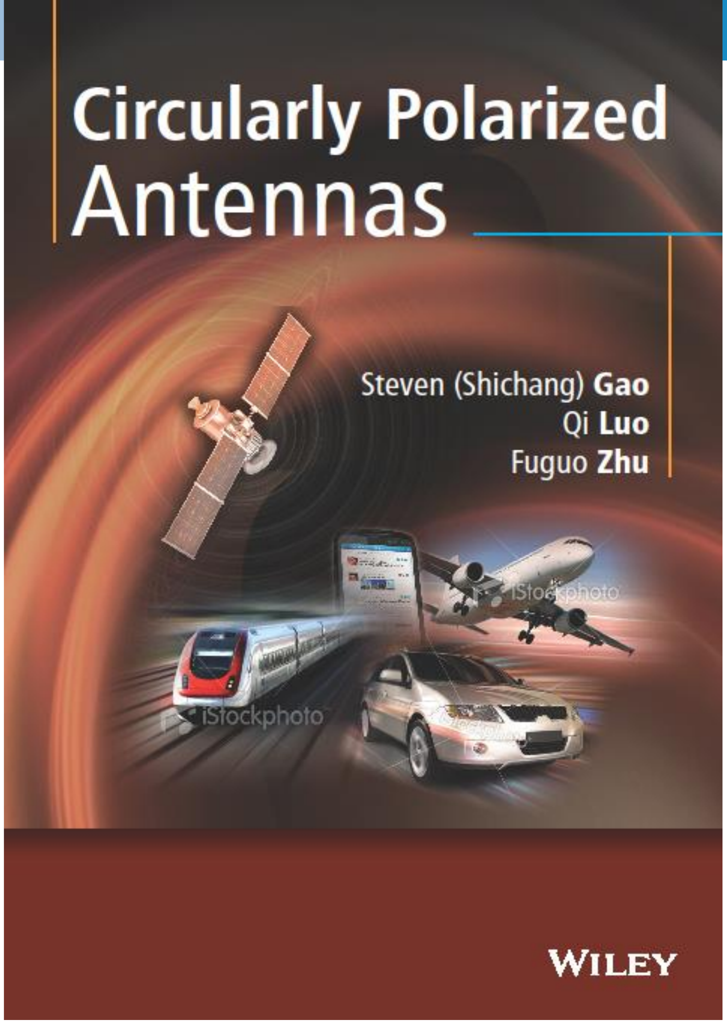
- A brief review of some recent developments in wideband CP antenna elements and arrays
  - This review is **NOT complete**. Apologies for being unable to include more examples due to limited space. More examples of CP antennas can be found in IEEE Xplore or my book
- In case studies, two recent examples including one wideband CP element using inverted-S element and one single-layer wideband CP high-efficiency reflectarray are described. Good performance is achieved
- Next steps: Wideband CP active phased arrays at mm-wave band and THz



Editors William A. Imbriale, Steven Gao and Luigi Boccia

Space Antenna
HANDBOOK

WILEY



Circularly Polarized
Antennas

Steven (Shichang) **Gao**
Qi **Luo**
Fuguo **Zhu**

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Thank-You!

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